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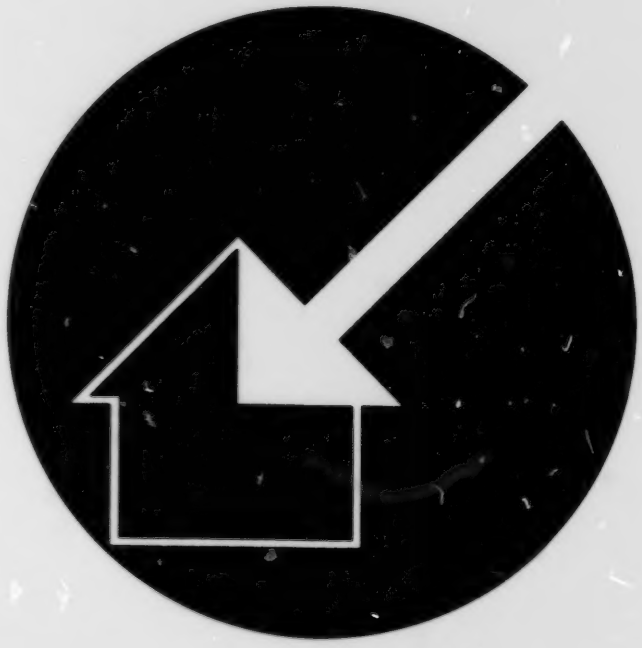
APPLICATIONS IN CANADA OF IEA SOLAR TASK VII

Central Solar Heating Plants With Seasonal Storage

James F. Hickling Management Consultants Limited

March 1986



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APPLICATIONS IN CANADA OF IEA SOLAR TASK VII

CENTRAL SOLAR HEATING PLANTS WITH SEASONAL STORAGE

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MANAGEMENT CONSULTANTS
LIMITED

Application in Canada of IEA Solar Task VII

Central Solar Heating Plants With Seasonal Storage

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March, 1986

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* Work performed by James F. Hickling Management Consultants Ltd. was done under contract to the National Research Council of Canada.

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Executive Summary

This report, "Application in Canada of IEA Solar Task VII", is a continuation of the International Energy Agency (IEA) Solar Heating and Cooling Programme, Task VII Central Solar Heating Plants with Seasonal Storage, Sub-Task II(b) Evaluation of Systems Concepts.

Previous work examined various techniques for the seasonal storage of solar energy including: aquifer, duct, tank, cavern and pit storage. Those analyses were performed using a uniform process and a set of assumptions, performance parameters, and economic variables common to all participating nations. This commonality allowed the relative advantages and disadvantages of a wide range of system configurations to be assessed. However, the common parameters do not represent reality in any particular country.

This is one of a number of national evaluations performed by participating countries which were intended to tie the analyses with actual site-specific national conditions. In each case, one or more of the highest-ranked systems (which could be applied at a chosen site) were selected from the previous analyses. The analysis was then repeated using local weather, performance and economic parameters.

The system chosen for application under Canadian conditions is based on the lowest cost system from the Sub-Task II(b) evaluation. This system has aquifer storage, low temperature distribution and a heat pump. Further differences between the Sub-Task II(b) analysis and the Canadian Application reflect Canada's particular situation. These include:

- Location,
- Costs,
- Tapwater load, and
- Collector parameters.

Three locations were examined which are likely to contain aquifers and which represent a selection of Canadian weather types. These were Toronto, Winnipeg and Fredericton. Energy prices (for electricity and the most economical auxiliary fuel) were differentiated on a regional basis. Costs were evaluated on a national basis for aquifers, distribution piping, and solar collectors. All other costs were common to the previous Sub-Task II(b) analyses.

Total load for 500 houses was defined as 10,000 MWh/annum for Toronto. The corresponding total loads using the same load model but different weather, were 10,947 MWh/annum in Fredericton and 13,524 MWh/annum in Winnipeg. The tapwater portion of the load was set at 600W per house for a total load of 2,628 MWh/annum. Collector parameters were based on Canadian made flat plate collectors. All other parameters and the methodology for analysis remained common with the Sub-Task II(b) analyses.

A number of preliminary analyses were performed to determine collector inlet temperature and heat pump condenser size. Then, heat pump evaporator size, collector outlet temperature and collector area were varied over successive runs. Results were plotted as solar cost versus solar fraction and the optimal system was defined as the knee of this curve at the point where solar cost begins to increase dramatically with solar fraction. The optimal systems defined in this fashion for each location then formed the basis for all further analytic work. For each of the optimal systems, an economic sensitivity analysis was performed by varying economic parameters by factors from 0.5 to 1.5.

The optimal systems found for the three locations were as follows:

Location	Collector Area (m^2)	Evaporator Size (kW/K)	Solar Fraction (%)	Solar Cost ($/MWh)	Total Cost ($/yr)
Toronto	12,500	200	68	52	673,000
Winnipeg	15,000	250	66	47	720,000
Fredericton	15,000	225	69	55	770,000

Incident solar radiation was highest at Winnipeg, however the severe weather conditions at that location resulted in higher heat losses such that the difference in collected energy per unit area of collector among the three locations was minimum. The difference in weather conditions and incident radiation resulted in different collector area designs at the three locations. The resulting match between collected energy and load was such that the three solar fractions were almost identical. The amount of auxiliary energy required at each location was also about the same. The higher load at Winnipeg was met with greater heat pump use. In spite of these higher energy requirements at Winnipeg, operating costs were the lowest because of lower energy costs. Capital costs were highest at Fredericton and Winnipeg because of their greater collector areas. The overall result was that total costs were lowest at Toronto, followed by Winnipeg and Fredericton. Economic parameter sensitivity analysis did not reveal any significant differences among the three locations.

Although cost effectiveness of the overall CSHPSS concept appears attainable when compared to an all electric alternative, central heating plants based on fossil fuel or alternative energy sources could be more cost effective. Seasonal thermal storage in aquifers may very well be cost effective in other applications or in CSHPSS systems under different economic conditions.

Résumé

Le présent rapport, "Application au Canada de l'activité VII sur les centrales solaires de l'AIE, fait suite au Programme de chauffage et de climatisation solaires de l'Agence internationale de l'énergie (AIE), Activité VII Centrales solaires avec stockage saisonnier, Sous-activité II b) Evaluation des concepts des systèmes.

Dans des travaux antérieurs, divers milieux de stockage saisonnier de l'énergie solaire ont été examinés: aquifères, conduites, réservoirs, cavités et puits souterrains. Ces analyses ont été effectuées suivant une méthode et un ensemble d'hypothèses, de paramètres de performance et de variables économiques communs à tous les pays participants, ce qui a permis d'évaluer les avantages et les inconvénients relatifs d'une vaste gamme de configurations de systèmes. Cependant, les paramètres communs ne représentent la réalité dans aucun pays particulier.

Il s'agit ici d'une des évaluations nationales faites par les pays participants dans le but de faire le lien entre les analyses et les conditions réelles dans certains endroits de chaque pays. Dans chaque cas, au moins un des systèmes les mieux cotés (applicables à un endroit donné) a été choisi à partir des analyses antérieures. L'analyse a ensuite été reprise avec des paramètres météorologiques, de performance et économiques locaux.

Le système retenu pour le Canada est le moins coûteux de ceux évalués dans la sous-activité II b). L'énergie est stockée dans une nappe aquifère, distribuée à basse température et extraite par une thermopompe. D'autres différences entre l'analyse de la sous-activité II b) et l'Application canadienne réflètent la situation particulière du Canada:

- Emplacement
- Coûts
- Besoins en eau potable
- Paramètres des capteurs

Trois endroits susceptibles de comporter des nappes aquifères et représentatifs du climat canadien ont été examinés. Il s'agit de Toronto, de Winnipeg et de Fredericton. Les prix de l'énergie (électricité et la plupart des combustibles d'appoint bon marché) ont été ventilés par région. Les coûts pour l'utilisation des nappes aquifères, les tuyauteries de distribution et les capteurs solaires ont été évalués à l'échelle nationale. Tous les autres coûts étaient les mêmes que ceux des analyses antérieures de la sous-activité II b).

La demande totale pour 500 maisons a été fixée à 10 000 MWh/an pour Toronto. Avec le même modèle mais des paramètres météorologiques différents, la demande totale a été établie à 10 947 MWh/an à Fredericton et à 13 524 MWh/an à Winnipeg. La partie de la demande pour l'eau de consommation a été fixée à 600 W par maison, soit un total de 2628 MWh/an. Les paramètres des capteurs sont ceux de capteurs plans de fabrication canadienne. Tous les autres paramètres et la méthode d'analyse étaient les mêmes que ceux des analyses de la sous-activité II b).

Des analyses préliminaires ont été effectuées pour déterminer la température à l'entrée des capteurs et la taille du condenseur de la thermopompe. Puis, on a fait varier, lors d'essais consécutifs, la taille de l'évaporateur de la thermopompe, la température à la sortie des capteurs et la surface de ces derniers. Les résultats ont été exprimés sous forme d'une courbe de coût de l'énergie solaire en fonction de la fraction solaire, et le système optimal a été situé dans le coude de cette courbe, au point où le coût commence à augmenter considérablement en fonction de la fraction solaire. Ainsi défini, le système optimal pour chaque endroit a ensuite été retenu pour fins d'analyse ultérieure. Une analyse de sensibilité économique a été effectuée pour chaque système optimal en faisant varier les paramètres économiques par des facteurs allant de 0,5 à 1,5.

Les systèmes optimaux retenus pour les trois endroits sont les suivants:

Endroit	Surface des capteurs (m^2)	Taille de l'évaporateur (kW/K)	Fraction solaire (%)	Coût de l'énergie ($/MWh)	Coût total ($/an)
Toronto	12 500	200	68	52	673 000
Winnipeg	15 000	250	66	47	720 000
Fredericton	15 000	225	69	55	770 000

Le rayonnement solaire incident a été le plus élevé à Winnipeg, mais le climat rigoureux à cet endroit s'est traduit par des pertes de chaleur si élevées que la différence entre les quantités d'énergie recueillies par unité de surface de capteur aux trois endroits étaient minimes. A cause des différences de climat et d'ensoleillement, il a fallu choisir des surfaces de capteurs différentes aux trois endroits. Les rapports entre l'énergie recueillie et la demande étaient tels que les trois fractions solaires étaient presque identiques. La quantité d'énergie d'appoint requise à chaque endroit était également à peu près la même. La demande plus forte à Winnipeg a été satisfaite par une plus grande utilisation des thermopompes. Malgré cette demande plus élevée à Winnipeg, les frais d'exploitation ont été les moins élevés à cause du coût moindre de l'énergie. Les coûts en captial ont été les plus élevés à Fredericton et à Winnipeg où les surfaces de capteur étaient plus grandes. En général, le coût total a été le moins élevé à Toronto; viennent ensuite Winnipeg, puis Fredericton. L'analyse de sensibilité des paramètres économiques n'a révélé aucune différence importante entre les trois endroits.

Même si le concept des centrales solaires avec stockage saisonnier semble rentabilisable comparativement à toute autre forme de centrale électrique, les centrales de chauffage à combustible fossile ou à d'autres formes d'énergie pourraient l'être d'avantage. Le stockage thermique saisonnier dans des aquifères pourrait très bien être rentable dans d'autres applications ou dans des centrales de chauffage sujettes à conditions économiques différentes.

ACKNOWLEDGEMENTS

The authors of this report would like to express their thanks to those who contributed to the analysis and the preparation of this report.

Dwayne S. Breger of Argonne National Laboratory was responsible for developing the methodology used to analyse the use of heat pumps in conjunction with aquifers. His contribution was part of the Canadian and American collaboration during the Task VII Sub-Task II(b) aquifer analysis undertaken previous to this National Evaluation.

The work performed by JFH was contracted by, and given direction by, Dr. T. LeFeuvre of the National Research Council of Canada. Similarly, funding for the U.S. participation came from Argonne National Laboratory under the direction of Dr. A. Michaels. The authors wish to acknowledge this support and thank their respective project leaders for their direction and comments.

The authors also wish to acknowledge valuable input, suggestions and comments from Dr. C. A. Bankston, the Lead Agent for Sub-Task II(b) and from Dr. E. L. Morofsky who is closely involved with the Government of Canada Building in Scarborough, Ontario, Canada, which has been designed to make use of seasonal storage in an aquifer. We also thank Landis Kannberg of Batelle Pacific Northwest Laboratories for providing useful data based on aquifers in the U.S.

We wish to thank the National Research Council for the opportunity of working with experts from eight other countries on this Task within the International Energy Agency R&D Programme. These experts all have contributed to this work through their participation and information exchange throughout Task VII.

1.0 BACKGROUND

1.1 THIS REPORT

This report, "Application in Canada of IEA Solar Task VII", is a continuation of the International Energy Agency (IEA), Solar Heating and Cooling Programme, Task VII, Sub-Task II(b) aquifer analysis. National Evaluations, using various storage methods, have been performed by most other participants in Task VII.

A companion publication, "Evaluation of Systems Concepts Based on Heat Storage in Aquifers"[12], is a precursor of this report. It presents a more general analysis of aquifer use based on parameters common to the other countries participating in IEA Task VII. Similar documents have been produced for duct storage[13] and stratified tank storage[14] by other IEA teams.

The following sections of this Chapter describe the International Energy Agency and the various tasks which have led to this report. Chapter 2 then summarizes the Task VII Sub-Task II(b) analysis which compares aquifer, duct and stratified tank storage. The Sub-Task II(b) results were used to determine which systems would be chosen for the further analysis, under Canadian conditions, contained in this report.

Chapter 3 discusses aquifers; what they are, where they are found, and how they are used for seasonal energy storage.

Chapter 4 describes what systems were chosen for analysis in this study. Also described are the parameters which are uniquely Canadian, in contrast to the parameters common to all participants used in previous IEA studies. These include climatic and economic factors.

Superscripts refer to references listed at the end of this report.

Chapter 5 describes the modeling of the systems; the tools used, the structure of the simulated systems, and the assumptions and techniques employed.

Chapters 6 and 7 outline the procedures used in the operational and economic analysis.

Chapter 8 summarizes the results of both the operational and economic analyses.

1.2 INTERNATIONAL ENERGY AGENCY

In order to strengthen cooperation in the vital area of energy policy, an Agreement on an International Energy Program was formulated among a number of industrialized countries in November 1974. The International Energy Agency (IEA) was established as an autonomous body within the Organization for Economic Cooperation and Development (OECD) to administer that agreement. Twenty countries are currently members of IEA, with the Commission of the European Communities participating under a special arrangement.

As one element of the International Energy Program, the participants undertake cooperative activities in energy research, development, and demonstration. A number of new and improved energy technologies which have the potential of making significant contributions to our energy needs were identified for collaborative efforts. The IEA Committee on Research and Development (CRD), assisted by a small Secretariat, coordinates the energy research, development, and demonstration program.

1.3 IEA SOLAR HEATING AND COOLING PROGRAM

Solar Heating and Cooling was one of the technologies selected by the IEA for collaborative effort. The objective was to undertake cooperative research, development, demonstrations and exchanges of information in order to advance the activities of all Participants in the field of solar heating and cooling systems. Several Tasks were defined in key areas of solar heating and cooling. A formal Implementing Agreement for this Program, covering the contributions, obligations and rights of the Participants, as well as the scope of each Task, was prepared and signed by 15 countries and the Commission of the European Communities. The overall program is managed by an Executive Committee, while the management of the Tasks is the responsibility of Operating Agents who act on behalf of the other Participants.

The tasks of the IEA Solar Heating and Cooling Program and their respective Operating Agents are:

I. Investigation of the Performance of Solar Heating and Cooling Systems - Technical University of Denmark

II. Coordination of R & D on Solar Heating and Cooling Components - Agency of Industrial Science and Technology, Japan

III. Performance Testing of Solar Collectors - Kernforschungsanlage Julich, Federal Republic of Germany

IV. Development of an Insolation Handbook and Instrumentation Package - United States Department of Energy

V. Use of Existing Meteorological Information for Solor Energy Application - Swedish Meteorological and Hydrological Institute

VI. Performance of Solar Heating, Cooling and Hot Water Systems Using Evacuated Collectors - U.S. Department of Energy

VII. Central Solar Heating Plants with Seasonal Storage - Swedish Council for Building Research

VIII. Passive and Hybrid Solar Low Energy Buildings - U.S. Department of Energy

IX. Solar Radiation and Pyronometry Studies - Amospheric Environment Services of Canada

1.4 TASK VII: CENTRAL SOLAR HEATING PLANTS WITH SEASONAL STORAGE

The objective of Task VII is to determine the technical feasibility and cost-effectiveness of solar/seasonal energy storage systems for large-scale district heating. The Participants will evaluate the merits of various components and system configurations for collecting, storing and distributing the energy, and prepare site-specific designs.

In colder climates, solar energy for heating of buildings is least abundant when it is needed most - during the winter. Seasonal storage is needed for making solar heat gained during warmer months available for later use. From investigations of various storage methods, two observations can be made: the choice of storage method will greatly influence the working conditions for, and the optimal choice of, the solar collectors and the heat distribution system; and based on the technology that is available today the most economic solutions will be found in large applications.

The work was divided into two phases, preliminary design and detailed design. The work during the first phase was undertaken in five Sub-tasks:

Sub-task I(a) Systems Studies and Optimization (Lead Country: Canada)

Sub-task I(b) Solar Collector Subsystems (Lead Country: USA)

Sub-task I(c) Heat Storage (Lead Country: Switzerland)

Sub-task I(d) Heat Distribution System (Lead Country: Sweden)

Sub-task I(e) Preliminary Site Specific System Design (Lead Country: Sweden)

A substantial effort in Sub-task I(a) went into the development of thermal and economic analytic tools.[1] At the end of Phase I, the common analytic tools were evaluated by applying them to several cases of interest to Participants[2]. These application cases were useful for assessing the range of applicability of the tools, the usefulness of the type of information they provided and the appropriateness of the level of detail of the simulation and economic models. The consensus of the Participants who undertook these application cases was that these analytic tools were appropriate for an extensive evaluation of a wide range of configurations on a common basis and such an exercise would be worthwhile in Phase II. The experience from the application cases undertaken pointed to several enhancements of the analytic tools which should be made in order to make that exercise most effective.

The Sub-task I(b) effort reviewed the performance, cost engineering data, and operating experience relevant to collector subsystems suitable for CSHPSS. The final report[3] provided the necessary performance models and cost data for flat plate collectors, evacuated collectors, parabolic troughs and central receivers used in the current work. In addition, the final report contained information on the design, installation, operation and maintenance of these collectors.

Three final reports were published as a result of the Sub-task I(c) work on thermal energy storage. Reference 4 presents basic engineering

information for different heat storage concepts that store energy in the form of sensible heat. It describes the heat storage concepts and their applicability to CSHPSS systems, reviews the status of the technologies, and presents a short technical compilation of some of the interesting projects in the participating countries. Reference 5 discusses simulation models that are available throughout the world for the analysis of seasonal sensible heat storage systems. It provides the basis for selection of the computer models that were used in the present study. Reference 6 summarizes the relevant cost data for seasonal sensible heat storage construction and provides the cost equations that were used in the economic analysis of this work.

The distribution of thermal energy to buildings by means of hot water was reviewed by the Sub-task I(d) Participants, and their final report[7] provides basic design and cost data applicable to a variety of systems in each of the participating countries. Information in that report is provided at the subcomponent level, i.e. pipe and fittings, rather than the subsystems level that was needed for the parametric evaluations of this work. The component data will be of great value in detail design.

The final sub-task of Phase I involved site specific design studies of CSHPSS systems in each of the participating countries[8]. The study, research, analysis and evaluation that went into the ten design studies provided a solid basis of expertise from which to launch the present study using a more refined methodology than was available during Phase I. In addition, as part of Sub-task I(e), the computer models and cost data on heat pumps were compiled.

The work in the second phase was divided into three sub-tasks:
Sub-task II(a) MINSUN Enhancements and Support (Lead Country: Canada)
Sub-task II(b) Evaluation of Systems Concepts (Lead Country: USA)
Sub-task II(c) Data Exchange (Lead Country: The Netherlands)

Phase II was intended to continue into detailed site-specific design for those Participants who chose to continue participation in Task VII.

Sub-task II(a) provided support to the use and enhancements of the computer program MINSUN. This program was the analytic tool used for most of the thermal and economic analyses performed in Sub-tasks I(a) and II(b). MINSUN, in turn, benefitted from research carried out under all of the Task VII sub-tasks. The MINSUN program is described in detail in reference 2 and summarized in Section 5.1.

Sub-task II(b) involved the analysis of systems for central solar heating plants with seasonal storage using three different types of storage: aquifer, water, and earth and rock[9]. Initial analysis was performed using common parameters. From these results some countries chose systems for further evaluations under their own national conditions. This report forms the Canadian National Evaluation. An overview of Sub-task II(b) is given in Section 2.

Sub-task II(c) provided the basis for an ongoing exchange of data relating to CSHPSS systems in participating countries. This basis is detailed in two sub-task documents entitled "Monitoring for Evaluation of CSHPSS Systems" and "Reporting Formats for CSHPSS Systems". Such an ongoing exchange of information is part of the recently approved third phase of Task VII.

1.5 TASK VII SUB-TASK II(b): EVALUATION OF SYSTEMS CONCEPTS

The objectives of Sub-task II(b) were:

- to examine a wide range of CSHPSS configurations, operational strategies, and load/location characteristics in order to compare and rank, from both a thermal and economic perspective, CSHPSS designs and applications;
- to recommend configurations, from those examined, which deserve further attention for specific applications and which are most unlikely to be economically attractive under specified assumptions;
- to make these findings readily available (subject to IEA restrictions) in the form of a major report and the presentation of one or more symposia for both technical audiences and decision makers; and
- to identify major uncertainties in analysis, modelling, or data and to coordinate with Sub-tasks II(a) and II(c) to resolve them or to develop plans for Phase III that will lead to their removal.

The range of system configurations analyzed in Sub-task II(b) was defined by the range that could be modelled with the MINSUN analytic tool developed within Task VII.

The principal focus of the analytic work was to identify system designs and design parameters which meet a given load at minimum overall cost. These optimum designs were to be examined using sensitivity analyses to identify the key parameters which affect performance, especially those parameters which vary significantly from site to site or which are currently uncertain.

The various configurations were analyzed under common assumptions and parameter values. The use of the same analytic tool (MINSUN) by all participants makes this commonality possible.

The analytic work in Sub-task II(b) was organized by team. Each of three teams analyzed one of the principal storage types: aquifer storage, water storage, and earth and rock (duct) storage. These teams are:

AQUIFER STORAGE	WATER STORAGE	EARTH AND ROCK STORAGE
Allan Michaels,	Heimo Zinko,	J.C. Hadorn,
Coordinator	Coordinator	Coordinator
U.S.A.	SWEDEN	SWITZERLAND
Allan Michaels	Heimo Zinko	J.C. Hadorn
Dwayne Breger	Tomas Bruce	Pierre Chuard
Landis Kannberg	Rune Hakansson	
Charles Bankston	Goran Hellstrom	
CANADA	DENMARK	CEC
Tom LeFeuvre	Kurt Hansen	Roger Torrenti
Verne Chant		
Ed Morofsky	GERMANY	NETHERLANDS
	Detlef Krischel	Aad Wijsman

The overall Sub-task II(b) effort was led by Charles A. Bankston of the USA.

1.6 NATIONAL EVALUATIONS

The reference case results of the Task VII Sub-task II(b) analyses were obtained by a uniform process using a common set of assumptions, performance parameters, and economic variables and two specific and distinct climatic conditions. These results do form a sound basis for assessing the relative advantages and disadvantages of the various configurations and subsystems in environments typical of most of the participating countries and for ranking the systems on a common economic basis. The common parameters and environments, however, do not represent reality in any country. The national evaluations are intended to supply a greater degree of reality and confidence in the findings by tying the analyses to actual site-specific national conditions.

The plan for the national evaluations calls for the national analyst to select one or more of the highest-ranked systems that could be applied at his chosen site (depending on availability of aquifer, granite, excavation technology, etc.) and repeat the analysis (optimization) using local weather and national performance and economic parameters selected by the analyst. This report presents the results of the Canadian National Evaluation.

An overview of Phases I and II of Task VII is given in the Summary Report[10].

2.0 TASK VII SUB-TASK II(b) SUMMARY

The basic study approach and methodology were adopted as a result of consultation among all Sub-task II(b) participants. A common methodology was essential in order to allow meaningful comparison of analytic results and to rank systems examined.

The large number of system configurations and parametric variations that could be considered within the constraints of the MINSUN code demanded that the first step in the project be the narrowing of choices to a manageable set. This was done by making use of the knowledge and judgment of the Task VII participants. Two methods were used. A formal hierarchical decision tree method in which the decision process is carefully structured, weighted, and evaluated with the aid of a microcomputer was used by half the group. The remaining half of the group followed a more traditional process of forming discussion groups to rank subsets of options (based on storage technology) and then to compare and combine those rankings in consensus-finding meetings. The results of the two processes were surprisingly similar. The agreement between the finding of the two expert groups strengthens the credibility of the process and the combined judgment.

A standardized input parameter list (presented in Appendix A) was developed to define a 'base case' as a common starting point from which all variations and optimizations could begin. The basis for selection was the database developed during the first phase of the work. Collector cost and performance parameters (with the exception of the uncovered flat plate) were taken from the Sub-task I(b) report[3], the storage data from the Sub-task I(c) report[4,5,6], the distribution systems data from the Sub-task I(d) report[7], the heat pump data from the Sub-task I(e) report[8] and the economic and system control parameters from the Sub-task I(a) reports[1,2]. Parameters specific to each storage technology, for example the number and spacing of bore holes in a

duct-earth storage systems, were specified by the analyst of that technology option and were usually derived through a subsystem optimization procedure. A series of standard variations from the base case was then defined and each variation was optimized.

The primary system classification determinants were:

Storage Type:

Water Storage - including insulated and uninsulated tanks, pits or caverns

Earth and Rock - including all forms of duct accessed storage in non-aqueous media

Aquifer - including natural and man-made aquifers for low and high temperature storage

Collector Category:

Low Performance - primarily stationary non-concentrating collectors intended mainly for low temperature operation

High Performance - stationary or tracking concentrating collectors; CPC, trough, and central receivers, or high performance, non-concentrating, stationary collectors (evacuated) capable of high performance at elevated as well as low temperatures

Distribution System:

Low Temperature - minimum delivery temperture of 50°C increased for ambient temperatures below 0°C at the rate of one-half degree per degree (i.e. delivery of 60°C at -20°C ambient) and return temperture of 30°C (60/50/30)

High Temperature - minimum delivery temperature of 80°C increased for ambient temperatures below 0°C at the rate of 1.75°C per degree (i.e. delivery of 115°C at -20°C ambient) and return temperature of 60°C (115/80/60).

Energy Conditioning:

Heat Pump - in series with load and auxiliary heating when needed

No Heat Pump - only auxiliary heating when needed

Load:

Size - total annual energy requirement or equivalent number of buildings

Profile - determined by climate, construction, energy use patterns, (e.g. of hot water)

The performance of various designs, defined by selecting from those major sub-systems listed above (storage type, collector type, distribution temperature, and heat pump or no heat pump), were examined for:

- a wide range of primary variables such as storage volume, collector area, temperature of collection, heat pump size,
- two different latitudes and climates (Madison, Wisconsin, USA, an example of a severe continental climate; and Copenhagen, Denmark, an example of a northern, maritime climate),
- range of auxiliary fuel prices.

Each variation from the base case was optimized for the following parameters:

- Collector area
- Collector outlet temperature
- Heat pump size (if included)
- Storage volume

Sensitivity analyses were performed for these additional variations:

- Load: 1 GWh, 10 GWh, 100 GWh per annum
- DHW Load: 0%, 20%, 50% of total load

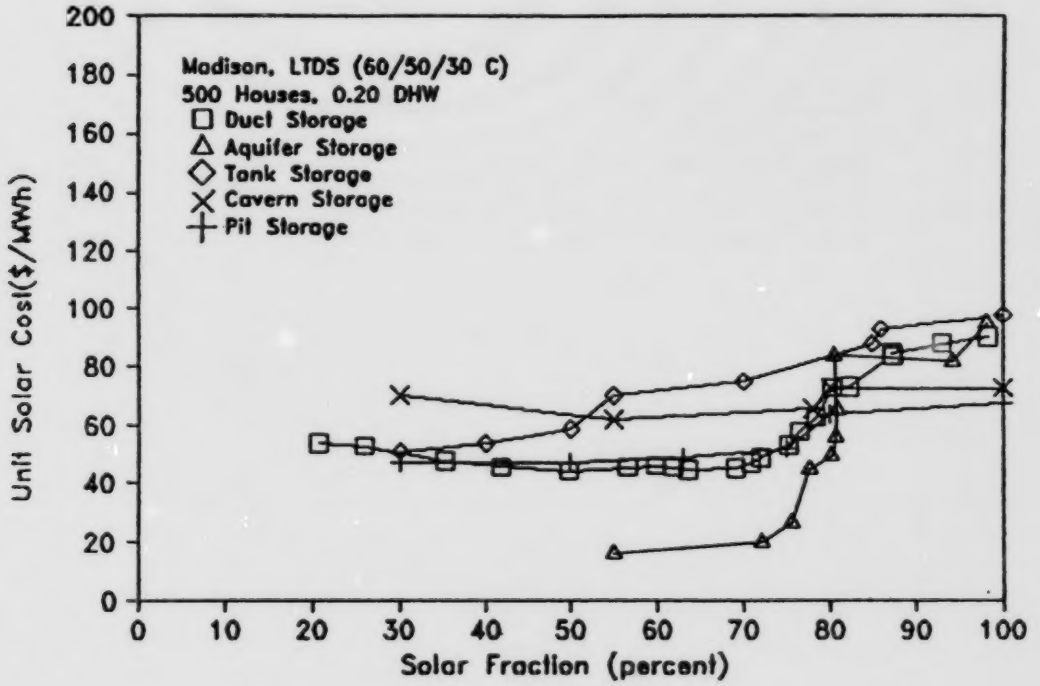
In the sensitivity analyses the results of the parameter changes were observed without optimizing the systems.

Unit solar cost and solar fraction were the primary indicators examined to evaluate performance. Other key variables examined included temperature of collection, volumes stored and retrieved, energy stored and retrieved, and total solar costs.

Figures 2.1 to 2.4 present the results of the Task VII Sub-task II(b) analysis. Results are for optimal systems using various storage techniques under two climatic conditions (Madison and Copenhagen) and two distribution temperatures (low and high).

It was found that aquifer storage is the least cost alternative at solar fractions below about 80%. Also, low temperature distribution is more economical than high temperature distribution. Solar costs as low as US$16/MWh were obtained.

FIGURE 2.1: COMPARISON OF MADISON LOW TEMPERATURE STORAGE ALTERNATIVES



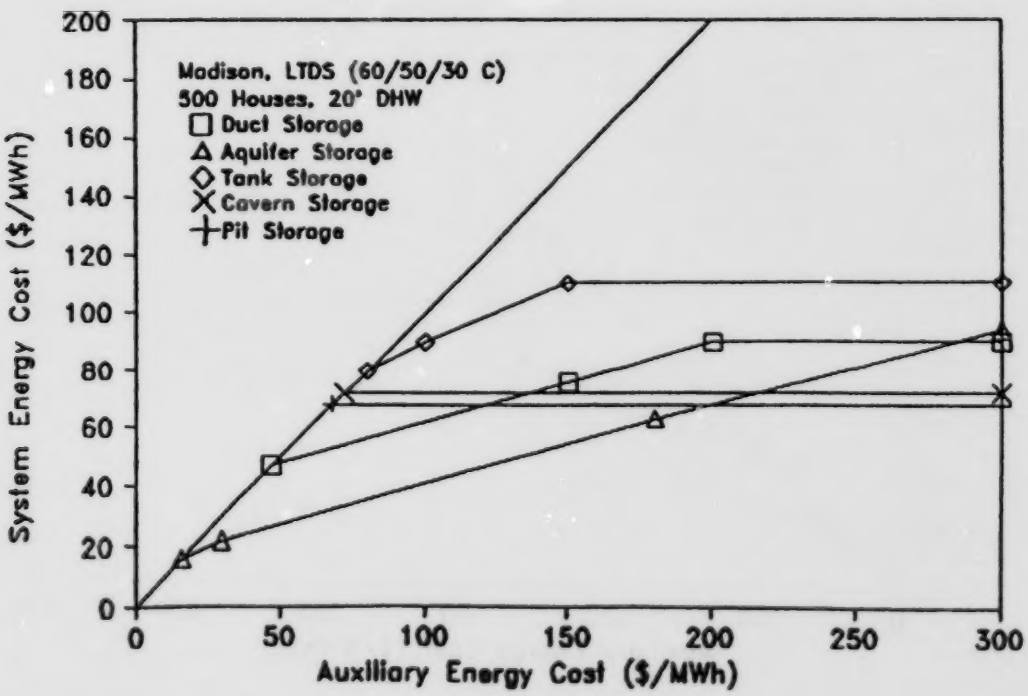
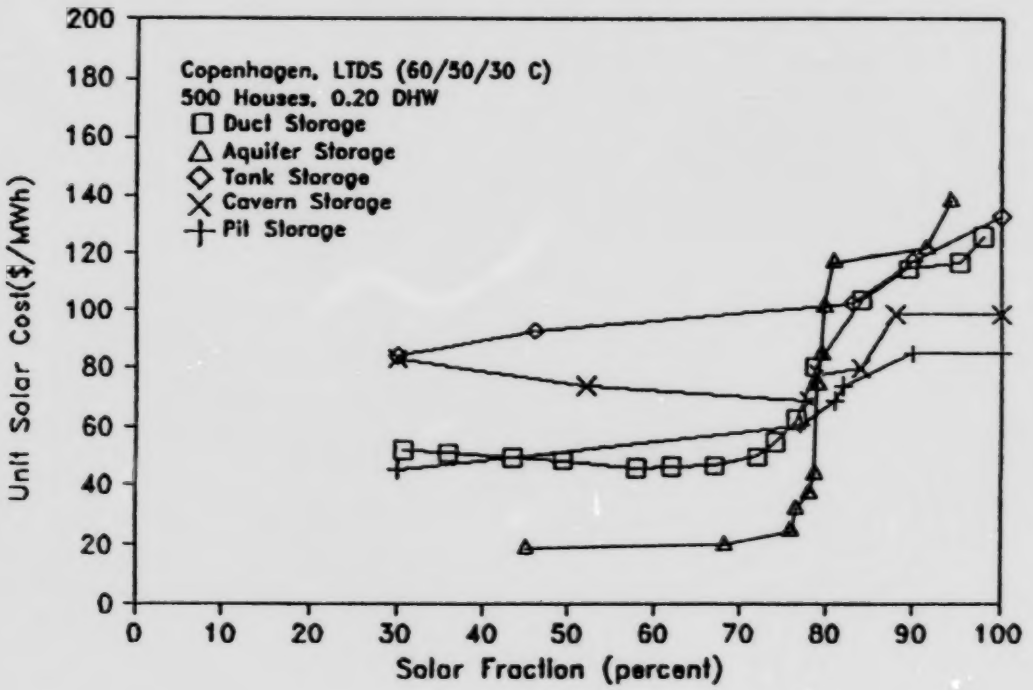


FIGURE 2.2: COMPARISON OF COPENHAGEN LOW TEMPERATURE STORAGE ALTERNATIVES



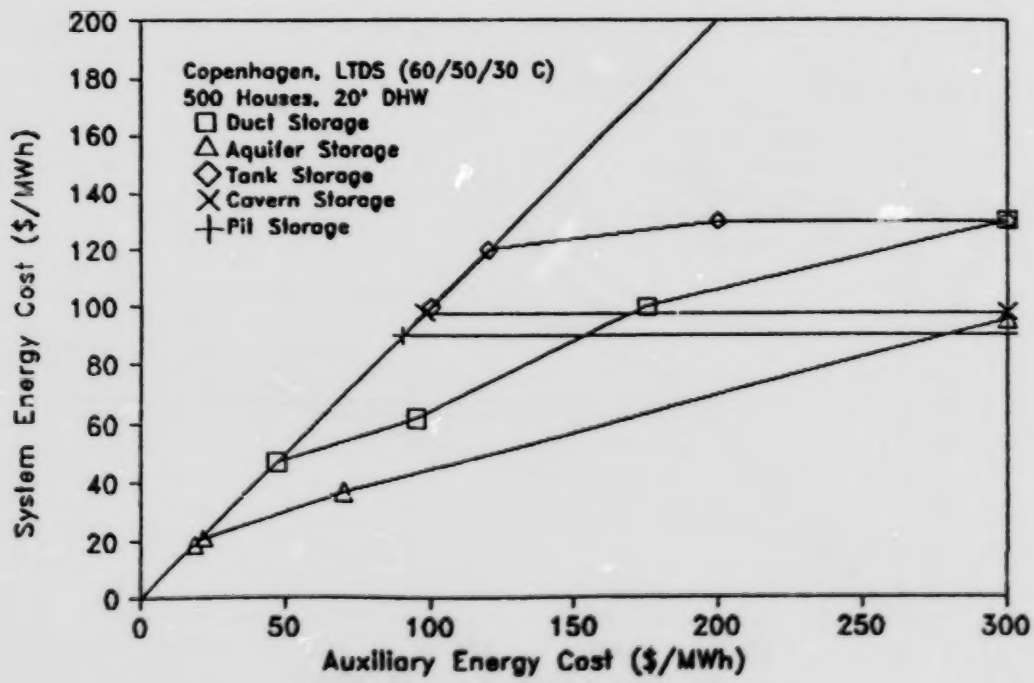
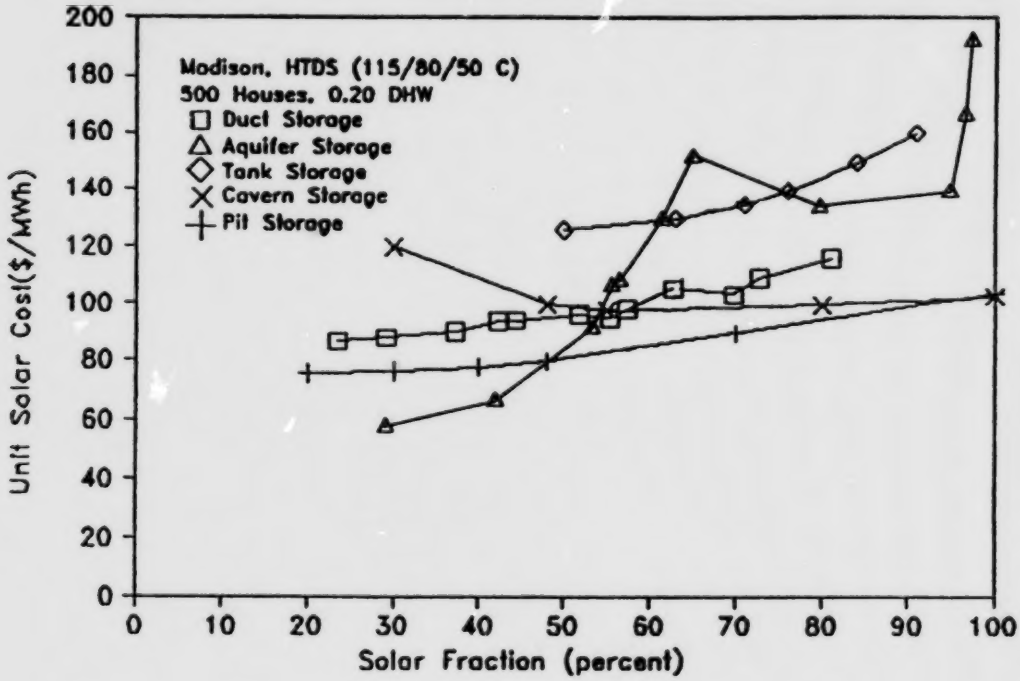


FIGURE 2.3: COMPARISON OF MADISON HIGH TEMPERATURE STORAGE ALTERNATIVES



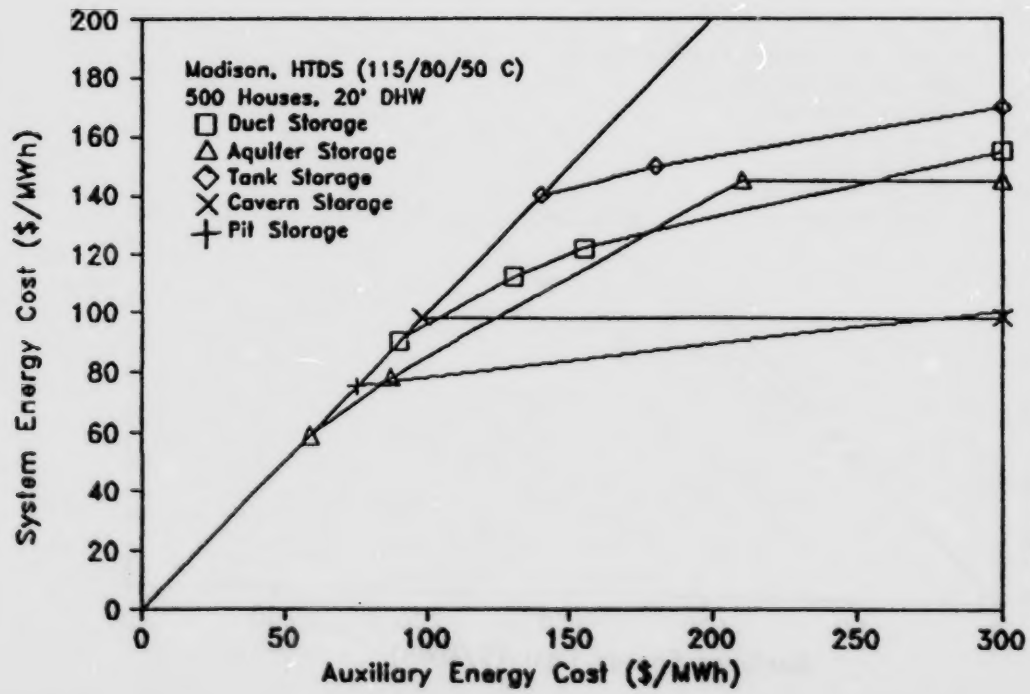
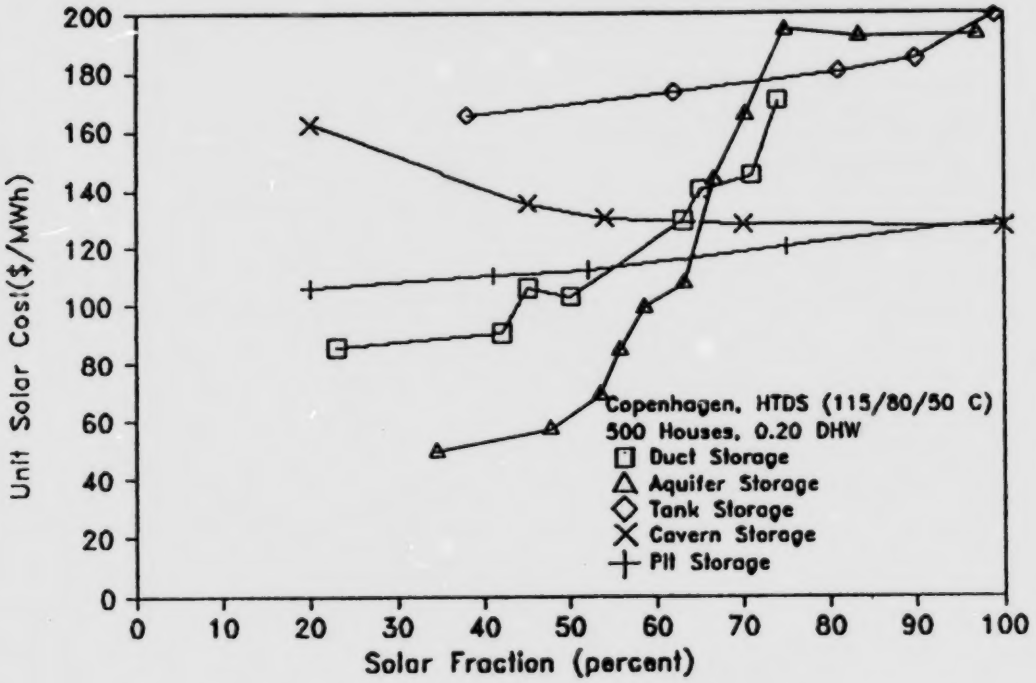
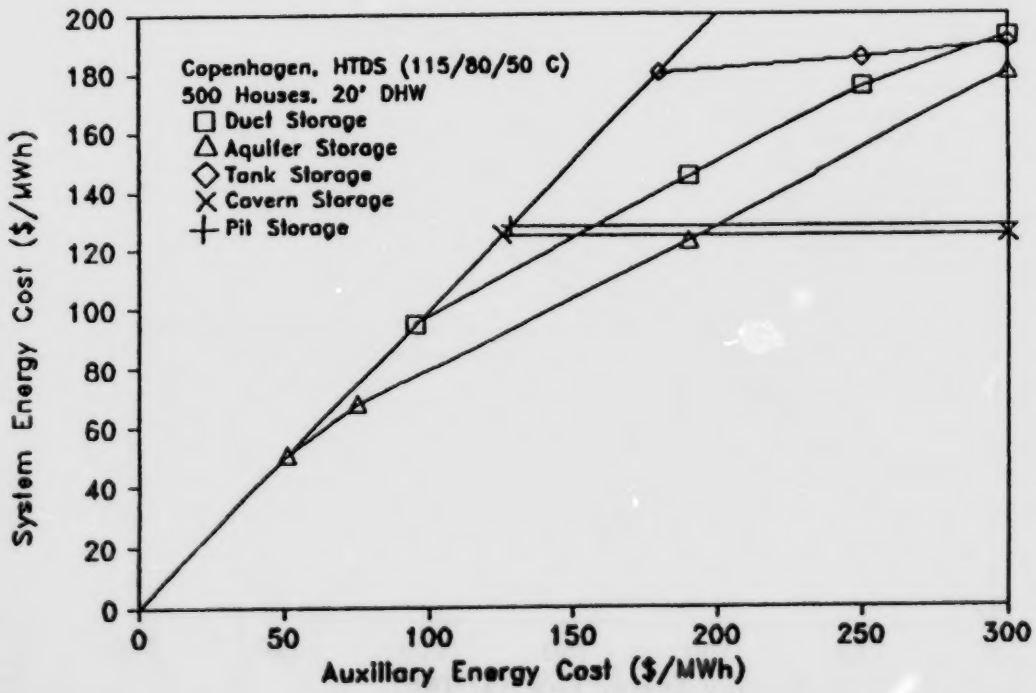


FIGURE 2.4: COMPARISON OF COPENHAGEN HIGH TEMPERATURE STORAGE ALTERNATIVES





3.0 AQUIFERS

3.1 STRUCTURE

Aquifers are separated into two major categories; bedrock and surficial. Bedrock aquifers are composed of consolidated rock of sedimentary, igneous, or metamorphic types which are generally older than tertiary. Surficial aquifers are composed of unconsolidated, granular, sedimentary overburden generally younger than tertiary age[16].

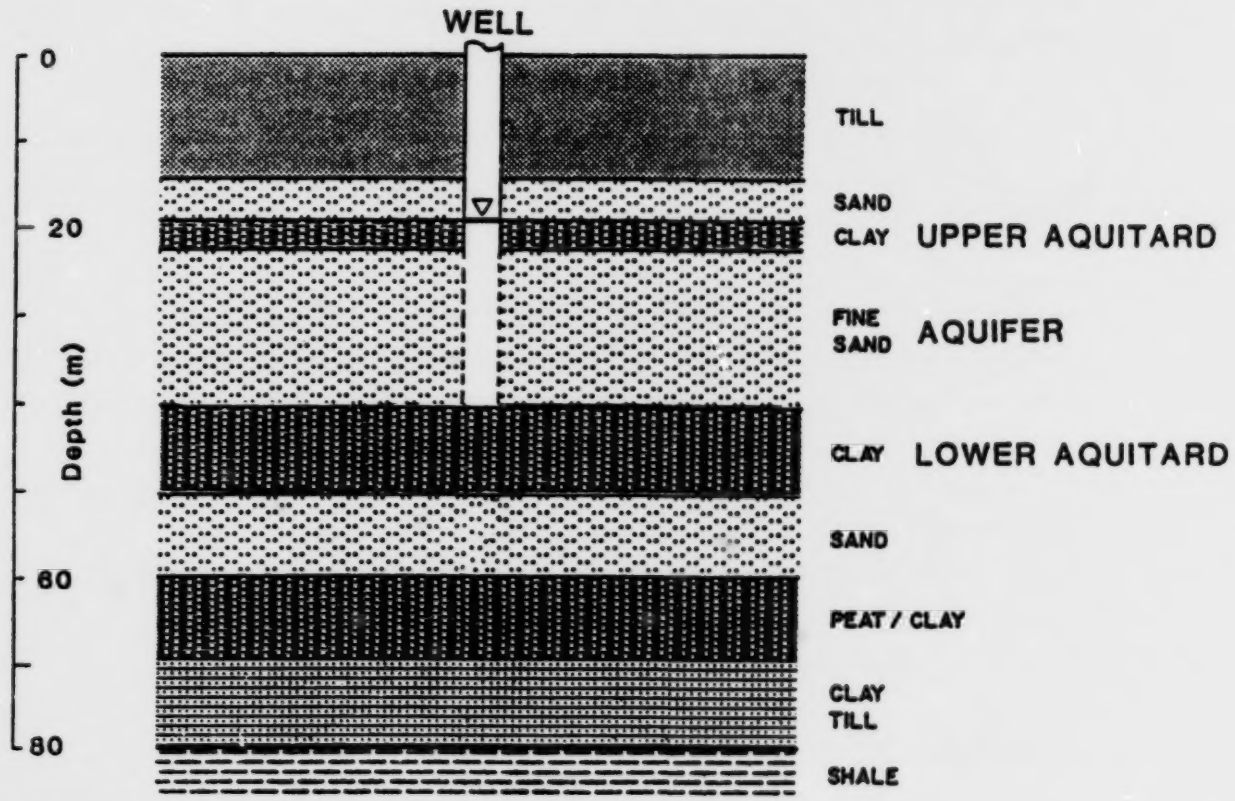
Only surficial aquifers are suitable for seasonal energy storage due to the need for a homogeneous and permeable matrix in which to distribute the energy to be stored.

An aquifer suitable for seasonal energy storage is composed of a layer of permeable material, confined by upper and lower layers of impermeable material (termed aquitards) as illustrated in Figure 3.1. The edges of the aquifer are unconfined. Water is injected and extracted through wells penetrating to the permeable layer. There is a thermal gradient at the interface between the injected water and the ambient water. The distance of this gradient from the well is called the thermal radius and defines the effective volume of the aquifer. This volume can vary from zero to a very large value limited only by the geology at the site.

3.2 PROPERTIES

Aquifer properties are highly variable and site specific. Properties are dependent on the type of material, the method of formation, the location, and local ground water conditions. Aquifer characteristics and parameter values used in this analysis are based on the lower Scarborough aquifer[17] near Toronto, Canada. These parameters are consistent with other known aquifers based on aquifer studies in the U.S. For modeling purposes, the aquifer is defined as follows:

Figure 3.1: AQUIFER CROSS-SECTION



Upper Aquitard - Thermal conductivity 2.75 W/mK
Heat capacity 1.5 x 10^6 J/m^3K
Thickness 20m

Aquifer - Thermal conductivity (horizontal) 2.0 W/mK
Thermal conductivity (vertical) 2.75 W/mK
Heat capacity 2.5 x 10^6 J/m^3K
Thickness 20m

Lower Aquitard - Thermal conductivity 2.75 W/mK
Heat capacity 3.1 x 10^6 J/m^3K
Thickness 40m

Initial Temperature - 10°C

3.3 OPERATION

A variety of techniques are available which use aquifers to supply energy. These are:

- direct cooling
- direct heating
- cooling storage
- heat storage

In direct cooling, the relatively low ambient ground water temperature (0°C - 11°C in Canada) is used as a cooling medium for space or process cooling. In direct heating, heat is extracted from the ambient ground water with a heat pump by lowering the water temperature a few degrees. With present heat pump technology, only use of water temperatures over 5°C and flows over 0.4 litres/second is practical. With either direct heating or cooling there are two methods of disposing of the water after its use: discharge to the surface or reinjection through another well to the aquifer.

Cooling storage involves the extraction of aquifer water which is cooled by some external means (cooling towers) and then reinjected. Later the cooled water is used to supply a cooling load. Similarly, heat storage involves the warming of aquifer water by external means (solar collectors) for later use against a heating load. Both cooling and heat storage circulate aquifer water between wells and do not produce any net loss of water.

For seasonal energy storage use, the aquifer is penetrated by two sets of wells. The number of wells in each set is dependent on the yield of each well relative to the flow rate required by the heating load.

There are two modes of aquifer operation: charging and discharging. During charging, water is extracted from one set of wells (the 'cold' well) and is warmed in the solar collectors. The water is then injected at the second set of wells (the 'warm' well) for storage. This continues for a period, typically all summer.

During discharging, water from the warm well is extracted and supplies heat to the building load. The water is cooled and is reinjected at the cold well. This process typically continues all winter.

Thus, aquifer water is continuously being shuttled back and forth between the two sets of wells. During the summer, water is extracted, warmed and reinjected. During the winter, the same water is extracted, cooled and injected again.

3.4 USE OF AQUIFERS IN CANADA

Use of aquifers to supply water for consumption and industrial processes is very common. There are a number of experimental seasonal aquifer energy storage sites in the U.S. and Europe. China has used aquifers for cooling since 1961. Aquifer use to supply energy needs (heating and cooling), however, is a new and evolving technology in Canada.

3.4.1 Previous Studies

A 1978-81 study for the National Research Council by MLM Ground-Water Engineering[16] examined the potential for direct heating from ground water in the Prairies, Ontario, and the Maritimes.

The reports examined the following concerns: existing heat pump technology, ground water occurrence and availability, ground water temperature and quality, and methods of water disposal.

The reports contained the following findings: Bedrock aquifers are extensive in all the areas studied, surficial aquifers are sporadic in the Maritimes and much of Ontario. Yields for all aquifers are highly variable. For environmental reasons, the order of preference for water disposal is:

- small diameter vertical injection well
- shallow large diameter injection well
- horizontal injection well
- surface infiltration panels
- surface discharge in drainage course.

The use of both cooling and heating through seasonal flow reversal provides improved economy.

A 1979 study for Energy, Mines and Resources by Hooper and Angus Associates Ltd.[18] examined the technical and economic feasibility of using aquifers as part of building cooling systems in Canada. Three techniques were considered: direct cooling with surface discharge, direct cooling with reinjection, and cooling storage.

Cooling with surface discharge was almost always found to be economically attractive since the only capital expense is a single well. This method is widely used, especially in the area of Winnipeg, Manitoba. There are, however, practical restrictions on the amount of cooling which can be

obtained because spent water is not returned to the aquifer. Depending on natural aquifer water renewal rates, the water level can seriously be depleted in the area of the well. Also excessive water disposal rates can be a burden on municipal drains and sewers.

Cooling with reinjection, having the additional expense of a re-injection well, was still found to be economically attractive. By returning water to the aquifer, the environmental problems of surface discharge are avoided. However, a gradual warming of the aquifer would be experienced unless natural ground water flow is sufficient to replace warmed water with natural cold water. The Hooper and Angus report found that this technique is currently under exploited in Canada.

Cold storage requires the greatest capital investment of the three techniques with the addition of a cooling tower (or mechanical chiller) and extraction capabilities at all wells. Also, the amount of water moved per unit of cooling is double the other techniques because water is extracted, cooled, and injected before being extracted again for use. The Hooper and Angus report found that this technique can be cost effective but that success is highly site specific. Some of the specific items which will affect this success include:

- existence of a suitable aquifer - fewer than 10% of aquifers are suitable. Extensive drilling, testing, and computer modeling is required to determine suitability

- a suitable building energy demand - The Hooper and Angus report concentrated on cooling, however, a heating demand could also be satisfied (by seasonal storage of solar energy for example). Peak loads which require auxiliary heating/cooling devices will reduce economic benefits. Since the capital expenditure is relatively constant in relation to load, large installations are economically favoured.

There are three major benefits of cold storage: 1) the environmental effects are very low; 2) heating as well as cooling, can be performed; 3) cooling energy retrieval is less dependent on aquifer flow characteristics than cold mining or water mining.

The Hooper and Angus report states that "the apparent effectiveness of cold storage suggests that a similar assessment of warm thermal storage be undertaken".

3.4.2 Aquifer Projects

The Valley East Recreation Complex, just north of Sudbury, obtains heat directly from an aquifer. Up to 16 litres per second of water are cooled from 6°C to 3°C by a heat pump at a COP of 3. Waste water is reinjected to the aquifer. Annual energy savings are approximately $19,000 a year.

A Westinghouse Canada Inc. plant at Renfrew, Ontario uses an aquifer to directly cool a large (12,000 m^2) gas-turbine components plant. The maximum flow rate is 34 litres per second. Annual energy savings are approximately $25,000 a year. Use of the aquifer for direct heating is also being considered.

There are currently only two aquifer energy storage sites in Canada. The Aquifer Thermal Energy Storage (ATES) demonstration at the Scarborough GOCB[17,19] is one of two field trials sponsored by the Department of Public Works as part of its seasonal energy storage program. The second installation is at the Atmospheric Environment Services (AES) building in Downsview, just north of Toronto[20,21].

The purpose of these trials is to evaluate and monitor the problems, performance, and economic viability of installing and operating a system for seasonal energy storage in an aquifer under Canadian climatic conditions.

The Scarborough GOCB, just recently completed, has been designed to take advantage of the latest energy management and conservation techniques, including ATES. The AES building is older (1972) and has ATES added as a retrofit installation.

4.0 CHOICE OF SYSTEMS

4.1 SUB-TASK II(b) AQUIFER SYSTEMS

The systems chosen for study in the Canadian Application are those which proved most economical during the Task VII Sub-task II(b) work entitled "Evaluation of Systems Concept based on Heat Storage in Aquifers."[12] The systems reported in that work had the following major characteristics:

- typical residential space and water heating loads (but with wide variation in the relative amounts of space heating and DHW requirements); varied in size by a factor of 100,
- aquifer seasonal thermal storage at a central location,
- large collector array at the central location; both low performance (glazed and unglazed flat plate) and high performance (stationary CPC) collector types,
- supply temperatures characteristic of low temperture (solar-oriented) design and high temperature (retro-fit) design,
- energy conditioning with a heat pump compared to no heat pump, and
- continental climate represented by Madison, Wisconsin, USA and Maritime climate represented by Copenhagen, Denmark.

Economic analysis of various systems concepts was performed on a present value basis. The most useful summary statistic of system cost performance was defined as annualized solar system cost divided by (useful) annual solar system heat output. The solar system cost included collectors, storage, associated pipes, controls, etc., and heat pumps (if any). Solar system cost did not include distribution capital costs or pumping costs. The useful heat output was defined as heat extracted from storage, delivered directly to the distribution network or to the heat pump evaporator. A marginal cost analysis was performed on the optimal system envelope for each of the weather/supply temperature combinations. Results were examined in terms of solar unit cost for a range of solar fractions.

It was clear that heat pump systems are generally more cost-effective than systems without a heat pump and that low temperature distribution is more economical than high temperature distribution.

For low temperature distribution with a heat pump the solar unit cost was in the range of 20-40 $U.S. per MWh for solar fractions in the range from 50% to approximately 80% (the remaining load was supplied by the heat pump input energy plus auxiliary heat if necessary). This heat supply cost range is comparable with conventional energy sources in many countries and in certain regions of the USA (New England States) and Canada (Maritime Provinces).

4.2 CANADIAN APPLICATION SYSTEMS

In the Canadian Application, an attempt has been made to maintain the common parameter values, assumptions and methodology used in previous IEA Task VII studies. Differences between the Sub-task II(b) analysis and the Canadian Application reflect Canada's particular situation.

From the previous work done for Sub-task II(b) it was clear that aquifer storage systems with low temperature distribution and heat pumps made the most economic sense and these, therefore, form the basis for evaluation in this study.

Changes were made to the Sub-task II(b) analysis parameters in the following areas:

- Weather
- Costs
- Tapwater load
- Collector parameters

These differences are summarized in Table 4.1 and described in the following sections.

4.2.1 Weather

Canada has many different climatic conditions. Three locations were chosen for this study; Toronto, Winnipeg and Fredericton. Each represents a different climatic condition and geographic area, and is considered likely to contain suitable aquifer formations. The locations are illustrated in Figure 4.1. Monthly summaries of hours of sunshine, temperature and heating degree days are contained in Table 4.2. Hours of sunshine and heating degree days are graphed in Figures 4.2 and 4.3.[15].

Winnipeg is situated in the Prairies and experiences continental weather patterns. There is already extensive use of aquifers to supply ground water for cooling.

Toronto's weather is strongly influenced by the Great Lakes. Aquifer energy storage is currently being implemented at two sites in Toronto.

TABLE 4.1: COMPARISON OF II(b) BASE CASE AND CANADIAN NATIONAL EVALUATION PARAMETERS

	II(b) BASE CASE	CANADIAN NATIONAL EVALUATION	
LOCATION	MADISON	TORONTO FREDERICTON WINNIPEG	
LOAD			
HOUSES	500		500
HEAT LOSS COEFF (W/m**2*K)	0.583		0.49
ENERGY(MWh)	10072	TORONTO	10047
		FREDERICTON	10947
		WINNIPEG	13524
TAP WATER (m/House)	460		600
COLLECTOR: TYPE	FLAT PLATE	CANADIAN FLAT PLATE	
AREA (optimized for each location)	10000	TORONTO	12500
		FREDERICTON	15000
		WINNIPEG	15000
STORAGE: TYPE	AQUIFER	AQUIFER	
SUPPLY TEMPERATURE(°C) (optimized for each location)	10		18
HEAT PUMP SIZE (kW/K) (optimized for each location)	250	TORONTO	225
		FREDERICTON	200
		WINNIPEG	250
COMPONENT CAPITAL COSTS	$ US		$ CAN
SOLAR COLLECTORS ($/m**2)	245		300
AQUIFER ($)	154000		250000
HEAT PUMP	201500	TORONTO	175000
		FREDERICTON	217000
		WINNIPEG	305000
AUXILIARY HEATER ($/W)	0.1		0.1
PIPING ($/m)	250		225
ENERGY COSTS	$ US		$ CAN
HEAT PUMP ELECTRICITY ($/kWh) (industrial sector prices)	0.07	TORONTO	0.0367
		FREDERICTON	0.0421
		WINNIPEG	0.019
AUXILIARY FUEL ($/kWh) (industrial sector prices divided by efficiency)	0.07	TORONTO (OIL)	0.0201
		FREDERICTON (OIL)	0.0245
		WINNIPEG (GAS)	0.0159

Fredericton is in the Maritime provinces, however, it does not have a true maritime climate due to its distance inland. Fredericton is one of the few sites in the Maritime region which may contain aquifers suitable for thermal storage.

Hourly weather files were obtained for each location from Atmospheric Environment Services. These drive the UMSORT section of MINSUN (see Section 5.1).

FIGURE 4.1: CANADIAN NATIONAL EVALUATION CITY LOCATIONS

TABLE 4.2: WEATHER

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	TOTAL
Hours Bright Sunshine													
Toronto	92	112	145	182	233	253	281	252	192	149	81	75	2045
Fredericton	106	124	140	154	200	206	233	221	167	138	95	93	1878
Winnipeg	121	144	176	220	226	276	316	283	185	152	91	93	2321
Mean Daily Temperature													
Toronto	-5.3	-4.9	-0.3	6.2	11.9	17.6	20.6	19.8	16.1	10.0	3.9	-2.5	7.8
Fredericton	-9.1	-8.3	-2.5	4.0	10.6	16.0	19.1	18.1	13.4	7.7	1.7	-6.4	5.4
Winnipeg	-19.0	-15.1	-7.8	3.6	11.5	17.2	20.2	18.8	12.8	6.6	-4.2	-13.7	2.6
Degree-Days Below 18													
Toronto	701	618	536	314	150	31	3	7	67	220	393	608	3646
Fredericton	843	745	633	419	229	79	20	37	153	326	498	758	4740
Winnipeg	1148	938	800	432	211	62	17	39	169	356	665	982	5819

FIGURE 4.2

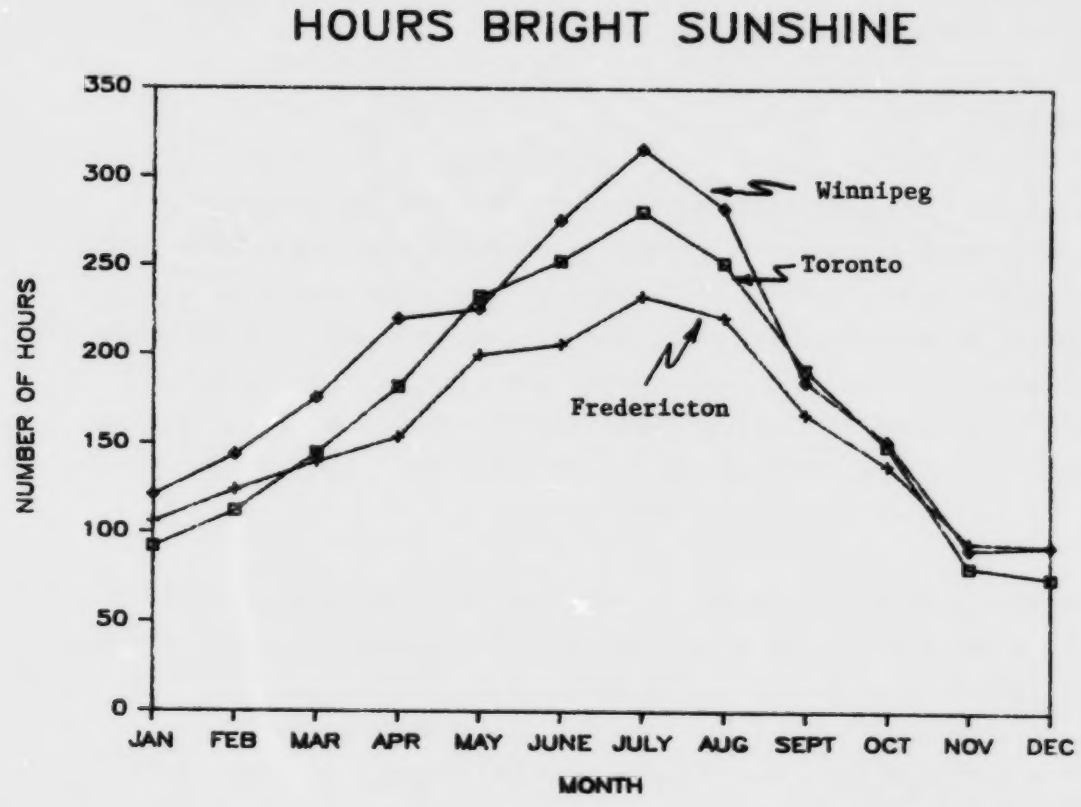
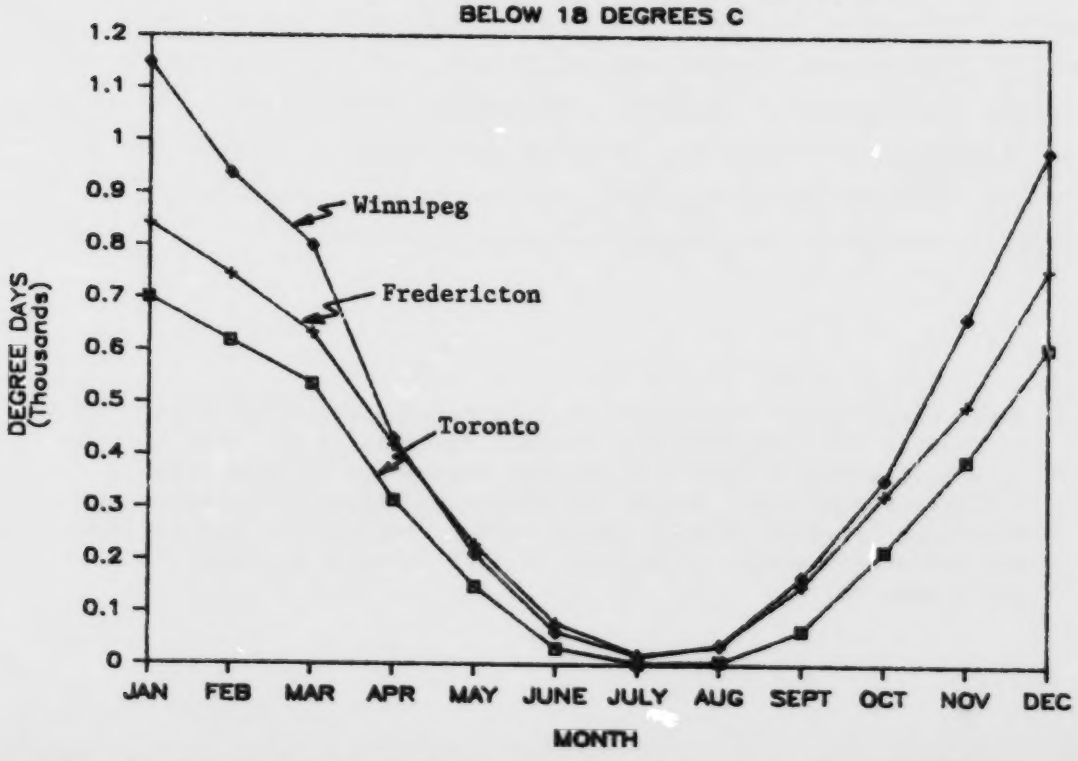


FIGURE 4.3



4.2.2 Costs

Aquifer

The cost of developing an aquifer for energy storage varies greatly depending on the physical properties of the aquifer and what is to be demanded of it. Cost is not related to the volume of storage or the amount of energy stored, as in most storage techniques. Rather, cost is related to the maximum flow rate necessary during charging and discharging which determines the required number of wells, pump sizes, pipe sizes, etc. Typical aquifer cost components are given below based on a 1979 study cited in the footnote.*

Aquifer potential is judged initially through records obtained from local wells and other ground water sources. This information is supplemented by test wells to determine the aquifer size, extent, and yield. A testing program in an area of unknown ground water potential may cost from CAN$5,000 for a low-yield well to CAN$25,000 for a high yield well.

Well cost is dependent on the well depth, diameter, and the ground composition. Diameter is dependent on the required yield and ranges form 150 mm for a yield less than 8 litres/second to about 400 mm for a yield of 90 litres/second. Development requirements to avoid fouling and to provide sand free water may involve additional cost. Table 4.3 contains approximate well construction costs for over burden and bedrock wells of typical 50 meters depth, according to diameter and probable yield, and including reasonable development and testing periods.

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*. These cost figures and others in this section are taken from: Study To Examine the Technical and Economic Feasibility of Using Aquifers as a Chilled Water Source or Storage Medium for Building Air Conditioning Systems, Volume II; Hooper and Angus Associates Ltd., Hydrology Consultants Ltd., April 1979. Prepared for Energy, Mines and Resources Canada. Costs are in 1978 Canadian dollars. (Reference 18)

Table 4.3 Well Development Costs

Dia (mm)	Yield (litres/second)	Cost ($/m)
150	8	225
200	20	325
250	30	610
300-350	50-75	810

At rates above 30 litres/second, the costs escalate rapidly and cannot be standardized due to the wide variability in development and screen requirements.

The costs of pumps, control devices, housings and other equipment may range from CAN$12,500 to over CAN$37,000 for a well.

A linear approximation to well cost estimates (40 m assumed depth) has been given in the reference as (1978 CAN $):

$$\text{Cost of n wells} = n \times \$8500/\text{well} + \$3.4 \times 10^5/\text{m}^3/\text{s} \times \text{total flow}$$

The cost of pumps, etc. for each pumped well is taken to be equal to the well cost. No additional equipment cost is associated with recharge wells.

Cost estimates used in this analysis are based on recent experience with the aquifer at the Scarborough Government of Canada Building and on recent U.S. experience. The estimates were adjusted to reflect the aquifer formation modeled in this analysis and a figure of CAN$250,000 was obtained.

Cost parameters within MINSUN were adjusted to obtain this value. Cost was therefore based on four wells, 40 meters deep, at CAN$1250 per meter, plus CAN$50,000 for equipment.

Distribution

Although detailed information for the design and cost estimation of heating distribution has been compiled, its use requires the specification of a great many variables characterizing the load, the relative position of the load components to the central plant, and the type of land (open fields versus developed, etc.).

For a given application, the distribution costs are constant and do not affect the economic analysis of central heating plants. For this reason the Sub-task II(b) analysis did not include distribution costs.

However, when comparing central solar plant options with distributed systems - either solar or conventional - distribution costs become important. So that this comparison can be made, some rough estimates of distribution costs have been included in this analysis.

The distribution cost estimates are based on a district heating study done for the Ontario Ministry of Energy[22]. That report indicated a cost of CAN$2,250,000 for the systems in this study. The parameters within MINSUN were adjusted to reflect this figure. The district heating network length was set at 5,000 meters with a diameter of 0.1 meters. Cost was set to CAN$1,750 per meter diameter per meter length plus CAN$50 fixed per meter length.

No distribution costs were associated with the separate tapwater system used for modeling purposes (see Section 5.3.4).

Heat Pump and Auxiliary Heater

A survey of heat pump and auxiliary heater prices did not indicate that Canadian prices would vary significantly from the Sub-task II(b) analysis values. These values were CAN$0.1 per Watt for auxiliary heater, approximately CAN$0.2 per Watt for the heat pump, and CAN$0.2 degrees Kelvin per Watt for each of the condenser and evaporator heat exchangers.

Solar Collectors

The collector cost of CAN$300/$m^2$ represents an all inclusive installed price for Canadian made collectors. This is based on extrapolation from the installation at the McLaren pulp and paper plant, Canada's largest at 2200 m^2 gross area.

Fuel

Fuel costs were obtained from an Energy, Mines and Resources energy price forecast.[23] Industrial sector prices were used as appropriate for a large central heating plant. Adjustments for efficiency and price escalation were made as recommended by the publication.

Electricity (100% efficiency) prices were as follows: Toronto 0.0367 $/kWh, Fredericton 0.042 $/kWh, Winnipeg 0.019 $/kWh.

The cheapest available auxiliary fuel was used for each city. In Toronto, oil (90% efficiency) was 0.0201 $/kWh. In Fredericton, oil was 0.0249 $/kWh. In Winnipeg, gas (85% efficiency) was 0.0159 $/kWh.

Economic Parameters

The economic parameters used by MINSUN were not changed from the values used in the Sub-task II(b) analysis. These were: depreciation time: 20 years; real interest rate: 5% per annum; fuel cost escalation rate: 2% per annum.

4.2.3 Tap Water Load

The typical domestic hotwater load is higher in Canada than Europe. Therefore the tapwater load was increased from 460 W/house to 600 W/house for the Canadian Application. This revised figure is based on energy demand scenarios developed for Energy, Mines and Resources, Canada.[24]

4.2.4 Collector Parameters

Collector parameters used in the Canadian Application are based on a Canadian built collector array currently in use. The collectors are flat plate, single glazed, selectively coated and insulated. The heat transfer medium is a 60/40 water and glycol mixture with a maximum flow of 0.02 kg/s m^2.

The performance of the Canadian and II(b) collectors are compared in Table 4.4.

TABLE 4.4 COLLECTOR PERFORMANCE

	Transmittance-Absorptance Product	Incident Angle Modifier Coefficient	Linear Heat Loss Coefficient
Canadian Collectors	0.753	0.1	5.25
II(b) Collectors	0.808	0.1	4.4

5.0 SYSTEMS MODELING

5.1 THE MINSUN PROGRAM

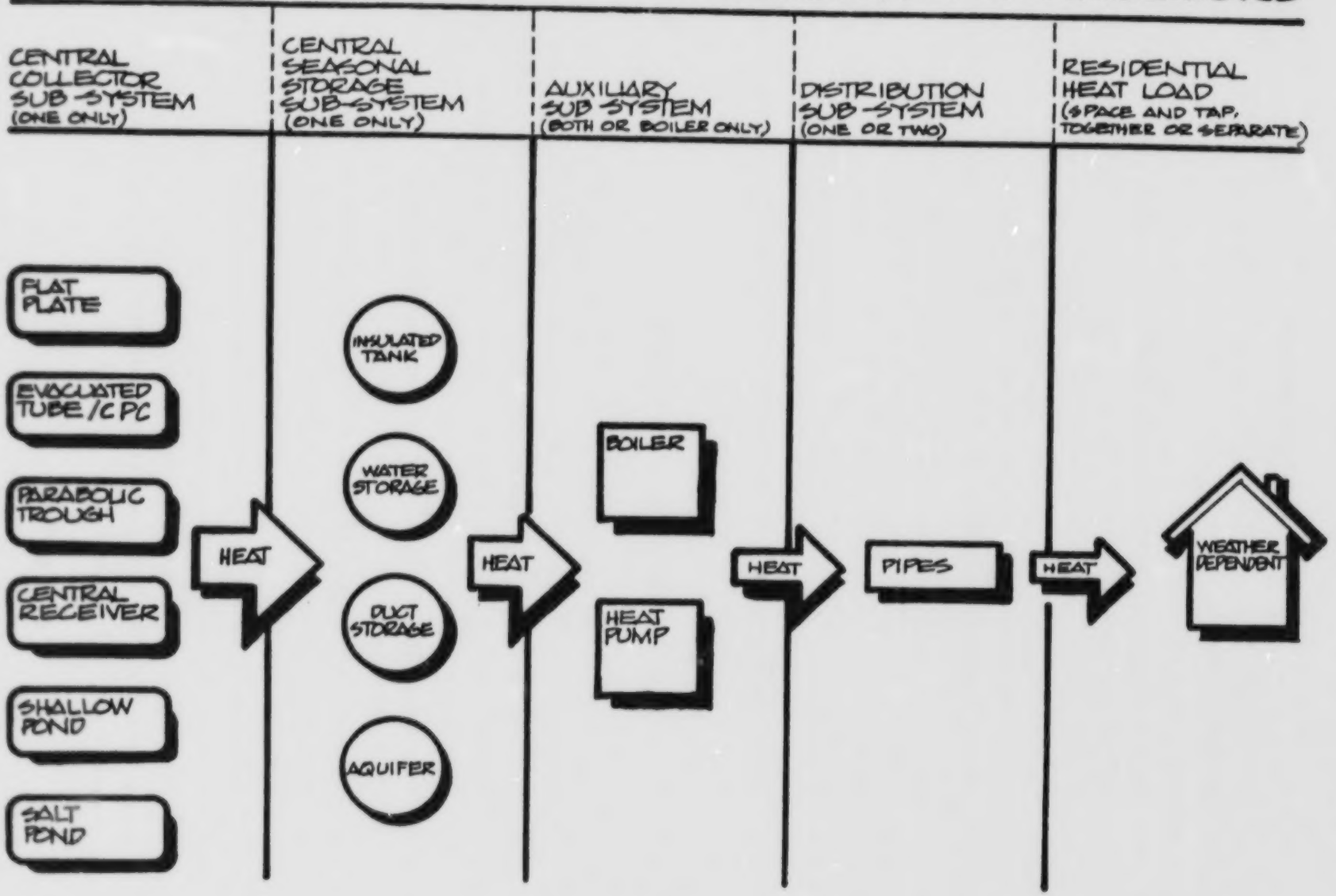
The MINSUN solar simulator is a set of FORTRAN programs that models a central solar energy heating system[2]. The programs provide for system thermal simulation, costing and economic analysis, and algorithmic optimization of selected system parameters. Subsystem capital costs are calculated by cost equations using user-specified parameters. Economic analysis combines capital costs and annual heat pump and auxiliary energy costs into an equivalent levelized annual cost using present value theory. Optimization is based on minimizing this levelized annual cost.

Each system is made up of several components. The components are solar collectors, thermal storage, heat pumps, auxiliary heaters, a network of connecting pipes, and residential heat load. There are several options for some of these components as shown in Figure 5.1.

5.1.1 MINSUN CSHPSS Configuration Options

The basic options that MINSUN is designed to accommodate are the subsystem types selected by Sub-tasks I(b), I(c) and I(d) within Task VII. The collector subsystem types accommodated are those selected by Sub-task I(b), i.e. flat plate, evacuated collectors (simple and compound parabolic concentrator collectors), parabolic trough, central receiver, and shallow pond. The seasonal storage subsystem types accommodated are those selected by Sub-task I(c), i.e. insulated water tank; water storage in underground tanks, caverns, or pits; duct storage systems in earth or rock; and aquifer systems. The auxiliary heat source options within MINSUN are either a boiler or a boiler and a heat pump. The distribution subsystem in MINSUN requires only design temperatures, flows and costs as provided by Sub-task I(d). The system load is calculated by MINSUN for residential space and water heating in a simple way taking account of daily average outdoor temperature, set-point, and simple heat-loss and heat-gain calculations.

FIGURE 5.1: BASIC OPTIONS WITHIN MINSUN SET OF SIMULATORS



5.1.2 MINSUN Execution Modes

The MINSUN program can be used both to simulate the thermal behaviour of a central solar energy system and to determine the optimum size of some of the components in the system. These two MINSUN characteristics provide three different modes for running the program - Single Simulation, Multiple Simulation, and System Optimization. All three modes require the engineering parameters of the system being modeled and weather information to drive the simulator. The three different modes are described below.

Single Simulation of a System Configuration

The simplest use of MINSUN is to perform a thermal simulation for a given, fixed configuration. All parameters of the system are defined. The program simulates the thermal behaviour, does the energy balance calculations, cost calculations, and generates output on the thermal and economic characteristics of the system specified. The thermal characteristics include a daily specification of heat flows among the major subsystems (from collectors, to and from storage, to load, losses, etc.).

Multiple Simulation of a System Configuration

MINSUN can perform several simulations in a single run while systematically varying the parameters defining the system. Only a limited number of result values are kept from each run. This mode is very useful for examining the effects of given input parameters on particular system results. It also uses less computation time than a large number of single simulation runs to get the same outputs.

Most of the calculations performed for this analysis used the multiple simulation option.

System Optimization

The MINSUN set of programs has the capability to automatically select optimum values for key design variables which minimize overall system levelized annual cost. The program uses a search procedure to vary the values of the appropriate design variables. It then simulates the thermal behaviour and computes the cost of the current system and compares it with that calculated in previous interactions. The program systematically closes in on the values of the design variables which minimize system cost. However, the computation time increases significantly as the number of variables optimized is increased.

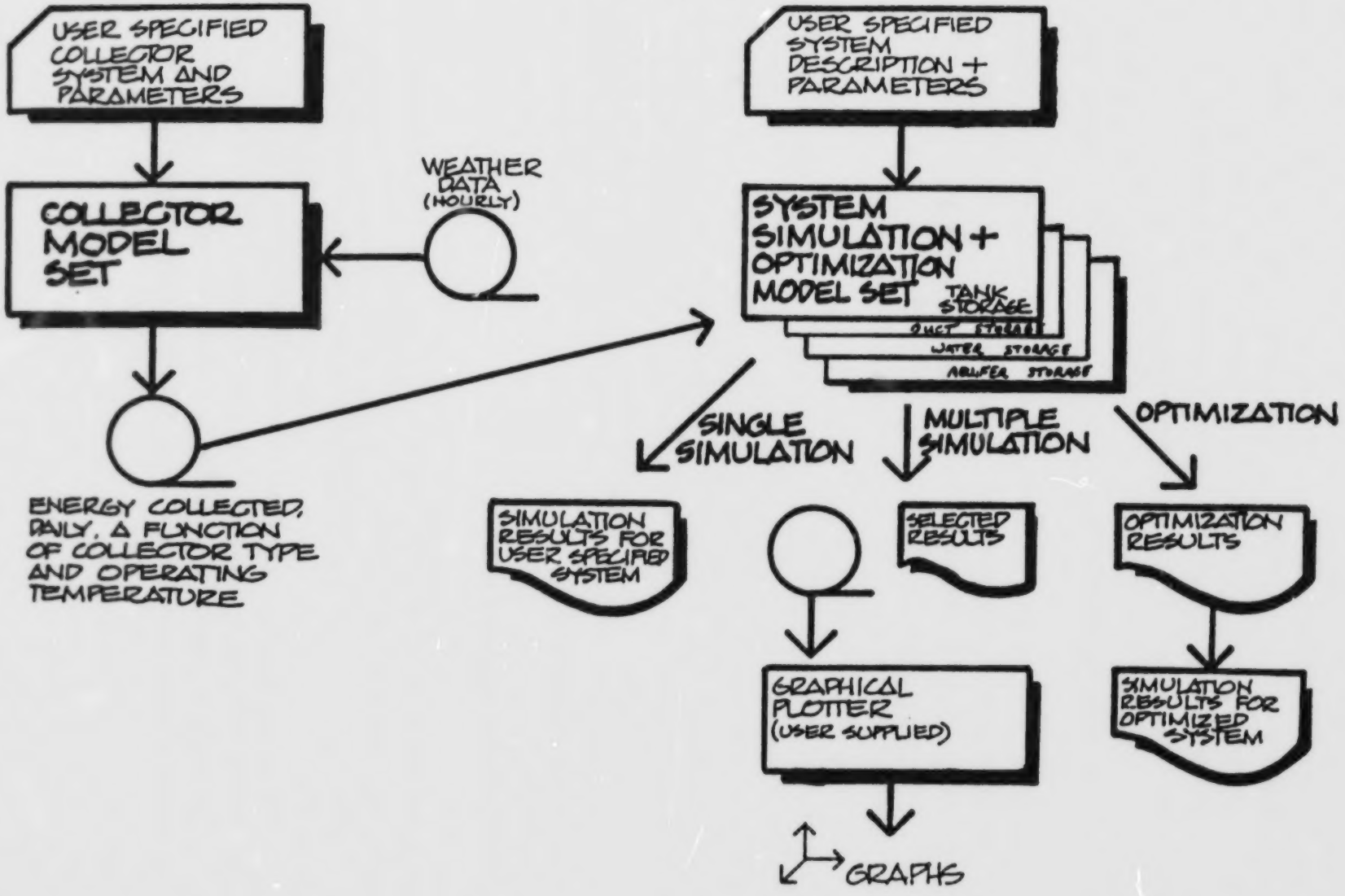
Once the optimum system, as selected by the optimization algorithm, is determined, the program performs a single simulation and calculates the thermal and economic characteristics.

Although the optimizer routine does work well on some systems, most of those analyzed in the present study exhibited rather flat and rough cost surfaces. Therefore, most of the calculations required for the present study were made using the multiple simulation option.

5.1.3 MINSUN Set of Programs

The MINSUN set of programs is illustrated in Figure 5.2. There are two separate main programs: the collector model set and the system simulation and optimization model set. The collector model set, which includes the UMSORT and ADVANCE programs, requires collector system parameters and other parameters. It then takes hourly solar radiation and temperature data and calculates the amount of energy that would be collected by a collector (per unit area) operating at a given temperature and the duration of operation on a daily basis. Several operating temperatures are used, and all results are stored for later use.

FIGURE 5.2: OVERVIEW OF **MINSUN** SET OF PROGRAMS



The system simulation model requires a large number (approximately 150) of system and other parameters. It simulates the thermal performance of a given system on an annual basis using one of the three modes as described above. Since the available storage models are large, there are separate programs for each storage type.

5.1.4 Component Models

The performance and cost models used for the collector, storage, heat pump, and load subsystems were derived from the information collected during the first phase of Task VII. The guidelines for developing the models were that the performance and costs should be those that could be expected for a system designed in 1984-85. Since most of the data were collected between 1981 and 1983, it was necessary to make some projections from the commercial products of 1981-83 to the anticipated products of 1984-85. This was done on the basis of the knowledge the participants had regarding the status and intensity of research and development and their judgment of probable cost trends based on their expectation of the market size and competitiveness. All costs were converted to U.S. currency and adjusted to 1980 values. The national evaluations, however, employ realistic cost and performance information on a site-specific basis.

Collector Subsystem Models

The basic information for the collectors was developed by Sub-task I(b) and implemented as a part of the MINSUN program by Sub-task I(a). The procedure employs empirical mathematical relations for the collector module output as a function of the orientation of the collector and the sun (e.g. incident angle modifiers for stationary collectors or single-axis tracking collectors), the temperature of the collector fluid, the ambient temperature, and the irradiance available to the collector (i.e. beam or global on collector plane). Daily energy outputs are

calculated from the hourly weather and the irradiance data for each site and stored in tables in UMSORT for a series of collector inlet temperatures spanning the operating range of the CSHPSS system. This calculation need be done only once for each site. The MINSUN main program obtains collector output for each day of the simulation by interpolating the table using the mean collector temperature, $(T_{in} + T_{out})/2$, as the independent variable. Since T_{out} depends on the collector output, an iteration loop is necessary. The time of collector operation during the day is found in a similar manner. The performance equation and the FORTRAN implementation for UMSORT may be found in Reference 3.

The thermal output of the collector module is adjusted using a set of Energy-Reduction Factors to account for the extra losses that result from combining a large number of modules into arrays. The factors were derived from a variety of analyses and empirical data by the Subtask I(b) participants. They represent an estimate of the annual energy delivery of a well-designed array of the specified module relative to the output of a single module. These reduction factors were used in lieu of the more accurate methods that would have required knowledge of such array details as row spacing, feeder and header pipe length, diameter and insulation, night time fluid volume, etc. An analysis of the results reported at the IEA Workshop on the Design and Performance of Large Solar Thermal Collector Arrays[11] indicated that these factors are in reasonable agreement with operational experience.

Aquifer Storage Model - AST

The model [25] simulates thermal energy storage in a confined aquifer. A single well is used for injection and extraction of water. The thermal processes in the aquifer and the surrounding ground are computed.

The aquifer is a porous layer in the ground, generally sand, that is surrounded above and below by impermeable material. MINSUN models a horizontal aquifer stratum of constant thickness. The thickness of the covering soil layers is also constant. The aquifer extends a long distance from the well in all directions.

The thermal properties of the aquifer are assumed to be uniform. The caprock (above the aquifer) and bedrock (below the aquifer) can each contain several layers with distinct thermal properties.

The height and depth of the aquifer and the expected radius of the thermally active region are given as input values to the model. The region of computation is extended radially outwards and vertically downwards until more or less undisturbed conditions prevail. During extraction ground water will flow into the aquifer through the outer boundary.

Figure 5.3 shows the grid used in a vertical cross-section of the ground to model the aquifer.

A finer grid spacing is used in the thermally active region near the well and at the boundaries between aquifer and caprock/bedrock. The spacing is increased strongly outwards and downwards.

The mesh is generated automatically. It is then adjusted according to the thermal properties in the ground, daily changes in loading conditions, and duration of the simulated time period. A finer grid spacing is used where large temperature gradients are expected.

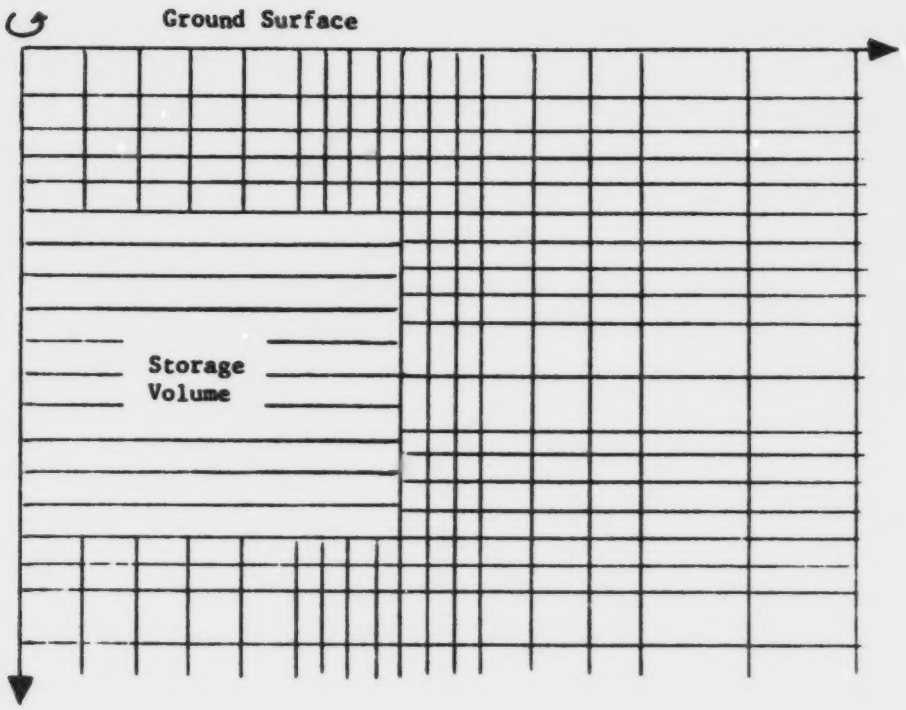


FIGURE 5.3

Example of SST Mesh in a
Vertical Cross-section of the Ground

A special problem with a simulation of an aquifer storage system is that the storage volume is unconfined. The thermally active region in the aquifer will vary according to external conditions. It is somewhat difficult to choose a mesh for the numerical calculation which is suitable for all possible evolutions of the thermally active region. MINSUN handles this problem by rerunning the simulation if necessary. For the first simulation, the mesh is generated using a thermal radius specified by the user. During the simulation, the true thermal radius - the maximum heat affected distance from the well - is calculated. If this calculated radius is not between 60 percent and 150 percent of the radius specified by the user, the simulation is redone using the new calculated radius to generate the mesh.

The convective-diffusive heat transfer process in the aquifer and in the surrounding ground is, for each time-step, simulated numerically in two separate parts: 1. Ordinary diffusive heat transfer, 2. Convective radial displacement with use of an entropy conservation technique.

The Solar Collector/Storage Loop

The amount of energy absorbed by the solar collectors depends on the temperature of the water supplied to the collectors. With the Aquifer model, water is assumed to be supplied to the collectors from a remote well which is not affected by the operation of the storage. The water is supplied at a constant temperature throughout the year and is always returned to the storage well.

The Heat Load/Storage Loop

The heat load consists of house heating and tap water heating. If separate distribution systems are used, the flow loops for these loads have the same structure, and they are coupled in parallel.

The water from the store, if warmer than the return water from the heat load, is supplied to the heat load. If the temperature of this water is lower than the demand temperature of the heat load, it is boosted to the right temperature by an auxiliary heater or a heat pump. If the fluid temperature from the store is warmer than the demand temperature, it is mixed with the return water from the heat load to yield the right temperature.

The Heat Pump Model

Heat pumps are used to transfer heat from a low temperature source (storage water) to a higher temperature receiver (house heating water). Work must be done to drive the system, but this energy is fully recovered as heat and usually represents less than a third of the total energy output of the heat pump.

The MINSUN control strategy assumes that, if the heat pump is used, the entire heating load is supplied by the heat pump. Therefore the power transferred in the condenser equals the heat load calculated elsewhere in the program.

If the entire load cannot be met with the heat pump, the heat pump is turned off and auxiliary power is used to boost the water supplied to the load to the correct temperature.

5.2 SYSTEM SCHEMATICS

The basic system configuration analyzed by the aquifer team is shown in Figures 5.4 and 5.5. Figure 5.4 illustrates, in simplified form, the real system to be studied. Figure 5.5 illustrates how this real system has been modelled with MINSUN using the options available in MINSUN but taking account of the assumptions imbedded in it.

As illustrated in Figure 5.4, the system load is defined primarily as a residential space heating and domestic hot water (DHW) load. The total load of interest ranges from 10,000 MWh to 13,524 MWh per annum. This load is assumed to be met entirely with a district heating system. The central heating plant for the district heating system includes the solar collector field, the seasonal thermal storage sub-system (aquifer), an auxiliary heater and a heat pump. As illustrated in Figure 5.4, the "real" system would have heat exchangers between the distribution system and the heating plant and between the aquifer and the rest of the system. As well, there would be a small buffer tank to allow for short-term optimization of heat transfer among the collector field, the aquifer and the heat pump/load.

As illustrated in Figure 5.5, the MINSUN version of the system schematic is somewhat different. For reasons of simplicity, the MINSUN configuration does not include either the buffer tank or the heat exchangers. The action of the buffer tank to smooth out the day/night peaks of solar collection and the load is essentially captured in the MINSUN model since it operates on a daily time step anyway. What is <u>not</u> modelled, however, is the option of serving load directly from the collectors (through the buffer tank). This capability is not currently available in MINSUN.

The MINSUN schematic varies in three other ways from the "real" schematic. Firstly, the MINSUN model does not take into account pumping power requirements. The extent to which the operation of the collector

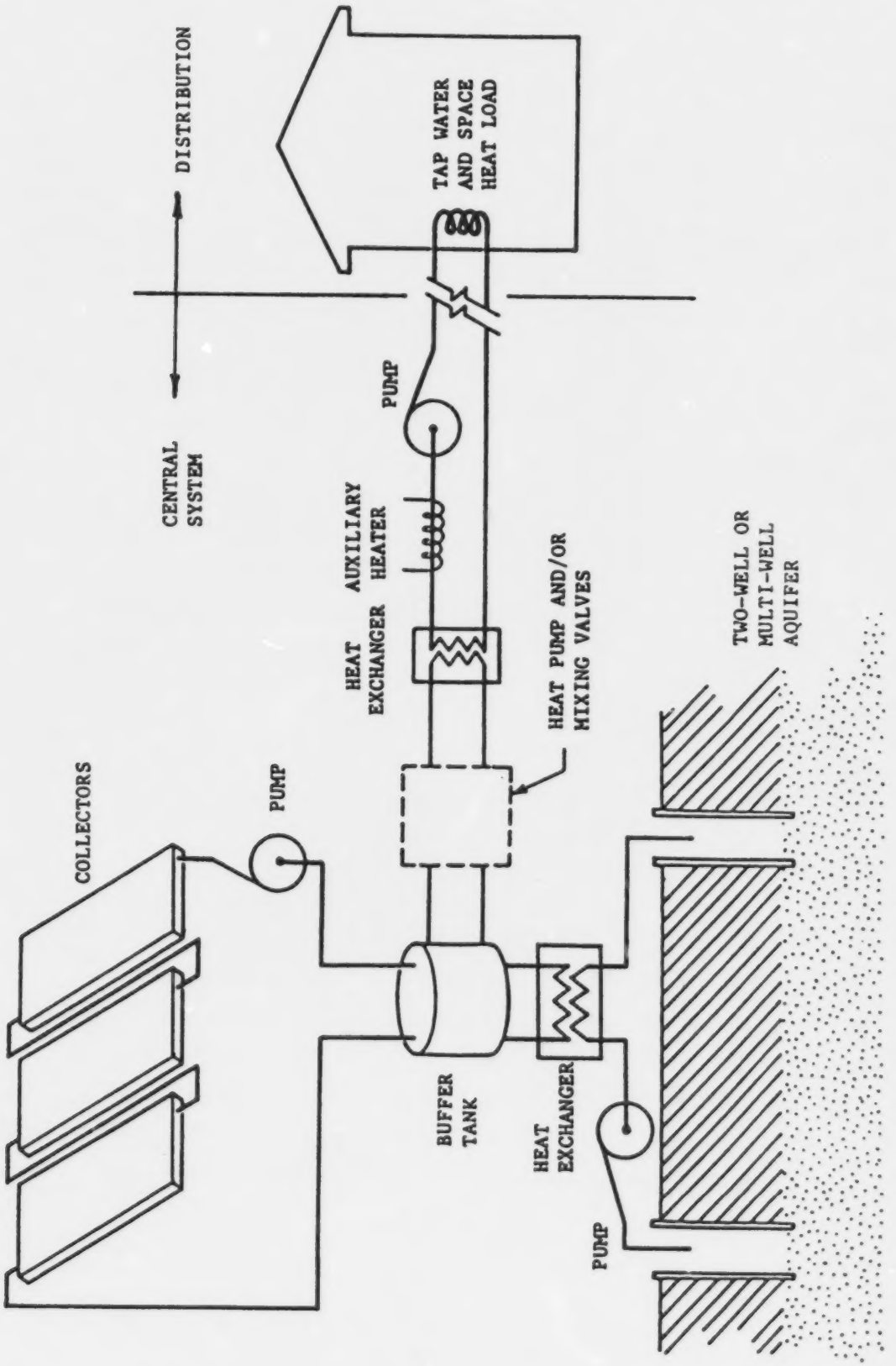
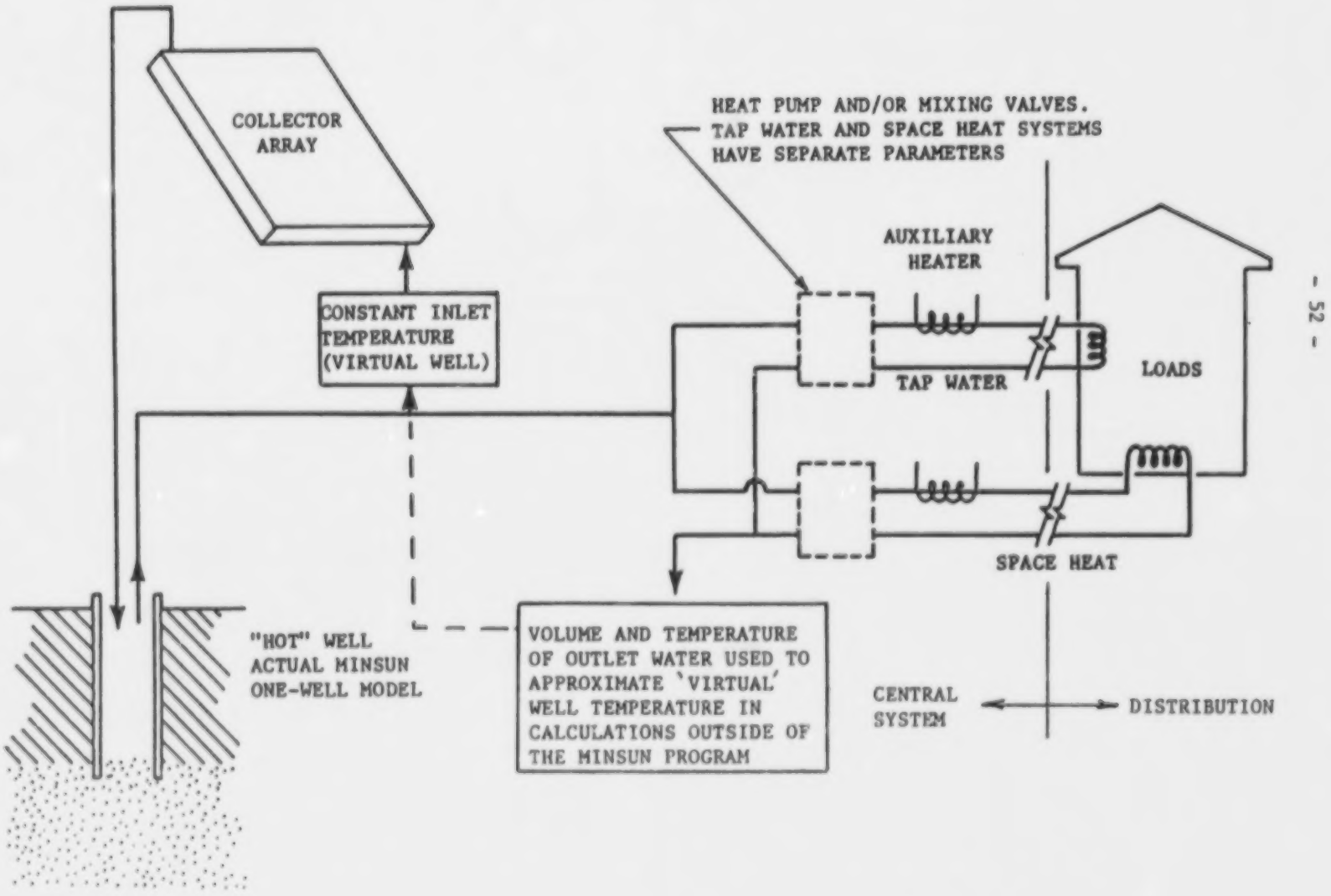


FIGURE 5.4: REAL SYSTEM CONFIGURATION

FIGURE 5.5: MINSUN REPRESENTATION OF SYSTEM CONFIGURATION


COLLECTOR ARRAY
HEAT PUMP AND/OR MIXING VALVES. TAP WATER AND SPACE HEAT SYSTEMS HAVE SEPARATE PARAMETERS
AUXILIARY HEATER
CONSTANT INLET TEMPERATURE (VIRTUAL WELL)
TAP WATER
LOADS
SPACE HEAT
"HOT" WELL ACTUAL MINSUN ONE-WELL MODEL
VOLUME AND TEMPERATURE OF OUTLET WATER USED TO APPROXIMATE 'VIRTUAL' WELL TEMPERATURE IN CALCULATIONS OUTSIDE OF THE MINSUN PROGRAM
CENTRAL SYSTEM
DISTRIBUTION

subsystem and the aquifer could affect the pumping requirements, and therefore the cost, is not modelled within MINSUN. Secondly, the MINSUN aquifer model is a one-well model. The "real" system would have at least two wells. A virtual one-well aquifer model has been employed to represent the real situation. Thirdly, the single distribution system for both space heating and DHW in the "real" system has been modelled in MINSUN with two separate systems. This was done to allow for a more flexible heat pump operational strategy than would be possible with a single system. These points are explained in more detail in Section 5.3.

5.3 MODELING ASSUMPTIONS AND TECHNIQUES

5.3.1 Collectors

The collector control strategy for use with the aquifer storage was set to provide a constant collector outlet temperature. This strategy was chosen since this type of storage operates essentially on a displacement principle such that the last water injected is the first water to be extracted. There is no gradual heating over the course of the summer as in a confined volume storage system.

5.3.2 Aquifer

The MINSUN program models only one aquifer which is positioned between the collectors and load. Water supplied to the collectors is received from a distant source at a specified constant temperature. The energy contained in the water returned from the load is not taken into account. This is unrealistic as the return water, being higher in temperature than ambient ground water, would in practice be stored in a second aquifer area for later supply to the collectors. In this study, the temperature of the distant source supplying the collectors has been set to the average temperature which would have been available had the return water from the load been stored. This is illustrated in Figure 5.5 as a virtual one-well aquifer.

The temperature of the virtual well depends on:

- load return temperature
- temperature loss during storage in the aquifer
- use of ambient aquifer water when the injected water is exhausted

The load return temperature is constant (user specified) if there is no heat pump and is dependent on heat pump operation when the heat pump is used. Preliminary model runs were made with various heat pump parameters and collection temperatures to determine average heat pump evaporator outlet temperatures. A relationship between aquifer temperature loss and return temperature was also established in advance from special MINSUN aquifer runs. When ambient water was used, its temperature was averaged with stored water temperature by volume. All of these calculations were performed outside the MINSUN model to determine the value of the collector inlet temperature parameter.

5.3.3 Pumping Energy Studies

The MINSUN program does not currently include a calculation of pressures, pressure drops, or pumping power. For most systems i.e. those involving tanks, caverns, pits, and most water-cooled collectors, the pumping power is known to be relatively small so these omissions are not a serious concern. Aquifers and duct storage systems, however, may introduce significant pressure drops and pumping reqirement. A brief preliminary study of the magnitude of these requirements was therefore conducted as part of the II(b) Aquifer report[12].

Rather than calculating pressure drops and pumping power directly from flow rates and the dimensions and characteristics of components, the study simply specifies the pressure drops for the major subsystems on the basis of typical systems examined or described in the literature. Three

configurations involving four subsystems were considered. The subsystems and component pressure drops are shown in Figure 5.6.

Energy requirements for three configurations have been calculated. Each configuration provides a different flow situation. These configurations are:

1. Aquifer storage with heat pump

2. Aquifer storage without heat pump

3. Tank storage without heat pump

Configuration 1 represents the heat pump case of this study. Configuration 2 represents a non-heat pump case. Configuration 3 represents a simple tank storage system for comparison with the higher pressure losses of aquifer storage.

Table 5.1 presents the results. Storage has been further separated into charging and discharging of the storage volume.

The pumping energy requirement varies from a maximum of 10.3 percent to a minimum of 1.5 percent of the total energy delivered to the load. These figures likely represent the upper and lower bounds for possible systems of this size.

Aquifer storage is by far the largest consumer of pumping energy, followed by distribution.

The amount of pumping energy required by systems of the size represented here is not sufficient to significantly affect the unit price of solar energy. However, consideration of pumping power would alter the design of optimum systems. After accounting for pumping requirements, optimum systems would use higher distribution temperatures and lower flow rates, and be smaller and more centralized using components of low restriction.

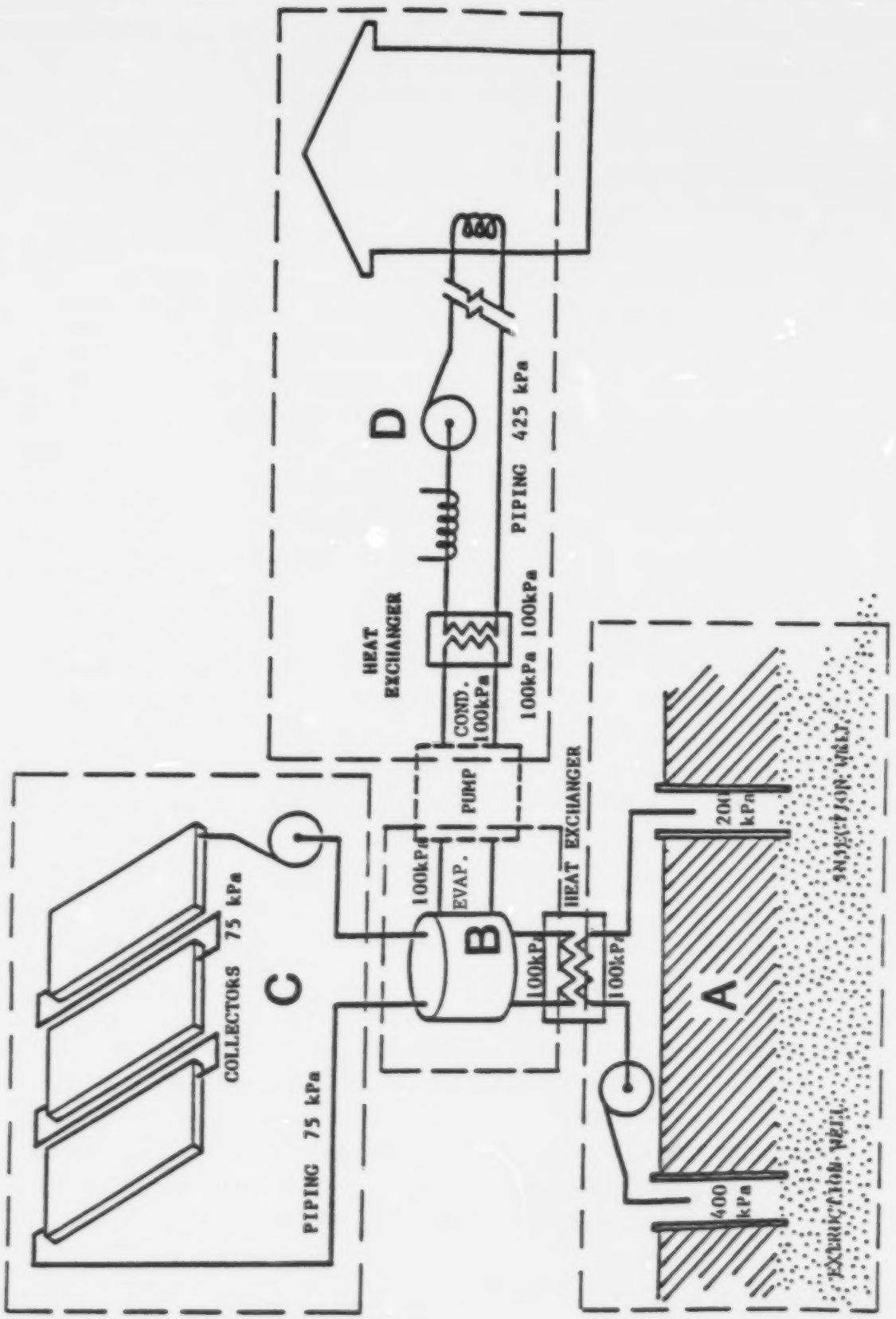


FIGURE 5.6: SUBSYSTEM SCHEMATIC

5.3.4 Heat Pump

The use of a heat pump with an aquifer system is different than with a tank. Once the water is removed from the aquifer to the evaporator it does not return to storage but is dumped (conceptually into a second "cold" well which is used for collector supply). It is thus important that the heat pump evaporator does not use large volumes of water with a small temperature drop across the evaporator. It is more efficient to have smaller volumes and larger temperature differences over the evaporator before it is dumped. The heat pump parameters appropriate for water and duct storage systems provide for a small delta T (approximately 3° C) and require very large flow rates. This may be satisfactory in the water and duct storage system since the water dumped from the evaporator goes back into storage. Because of this difference, heat pump design parameters are more important in the aquifer systems.

The heat pump model in the aquifer version of MINSUN is operational only with the constant evaporator flow option. If one heat pump system were used to meet both the house heat and DHW loads, the flow would have to be large enough to meet the winter load, and large volumes would be removed from the aquifer to meet the small summer DHW load with only a small evaporator delta T. To avoid this problem, the separate tapwater system (TAPW option) was used to specify a second set of heat pump parameters for the DHW load. Conceptually, this would be the same heat pump operating at a different flow rate but similar delta T. The smaller heat pump in the tap water system supplied the domestic hot water demand so that the main heat pump was idle during the summer. This was done to simulate actual operating strategy where the main heat pump represents a number of heat pumps in parallel, and the tap water heat pump represents the summer operating condition where the number of operating units is reduced. The tap water system has no costs associated with it.

6.0 OPERATIONAL ANALYSIS PROCEDURES

The analysis approach used for the Canadian Evaluation follows, very closely, the method used for the heat pump cases of the Sub-task II(b) aquifer analysis.[12]

The space heating load for Toronto was defined to be 10,000 MWh/annum for 500 houses of 300 m^2 each. This is the same as the Sub-task II(b) base case. The house heat loss coefficient was then varied, through iterative MINSUN runs, to obtained this load under Toronto weather conditions. The heat loss coefficient was determined to be 0.490 W/m^2K.

The load definition (number of houses, area, and heat loss coefficient) was held constant for the other cities with the effect that their space heating loads vary according to the severity of the local weather loads. These loads were 10,947 MWh in Fredericton and 13,524 MWh in Winnipeg.

Changes were made to the Sub-task II(b) base case parameter values in order to develop typically Canadian systems. Three systems were analyzed; Toronto, Fredericton, and Winnipeg. Parameter changes were required for:

- Weather
- Costs
- Tapwater Load
- Collector Parameters

These changes are outline in Section 4.2.

A preliminary consideration unique to the aquifer system is the user specified collector inlet temperature which in MINSUN remains constant throughout the year. In the operation of the aquifer system the heat pump evaporator dump water is injected into a second distant well.

This "cool" aquifer well is used to supply the collectors and its annual average temperature has been aproximated as follows. From the evaporator dump temperature is subtracted a pre-determined temperature loss due to storage. If the evaporator dump volume is less than the injected volume, the dump temperature is "diluted" with the differential amount of injected volume coming from the ambient 10°C aquifer supply. The evaporator dump temperature is a function of the storage temperature and evaporator size (or delta T). The simulation results show the dump temperature to be much more strongly dependent on storage temperature since the differences in the evaporator delta T's were not very significant and were somewhat evened out after the storage temperature losses were accounted for. The following table summarizes the MINSUN determination of the storage temperature losses.

AQUIFER TEMP (°C)	TEMP LOSS (°C)
50	14
40	9
30	3.5
20	0

The assumptions made for the collector inlet supply temperature as a function of outlet temperature is shown below:

COLLECTOR OUTLET TEMP (°C)	COLLECTOR INLET TEMP (°C)
15	10
20	10
30	16
40	20
50	21

For the aquifer storage option the heat pump can only operate in the constant flow mode due to present program limitations (a constant evaporator outlet temperature option is available for other storage sub-systems). As discussed in Section 5.3.4, it was necessary to specify a separate set of heat pump parameters for the domestic hot water load since this small load must be met with a low flow rate from the aquifer to conserve volume.

Optimization of the heat pump subsystem is reached through adjustment of the evaporator and condenser heat transfer capacity parameters (with constant flow these values are also directly related to flow rates).

Four parameters had to be chosen for the analysis and each is a subject for optimization. These are the evaporator and condenser heat transfer capacities for both the tapwater and space heat distribution systems. The condenser side of the heat pump is aware only of the load and not the heat source. Therefore, this parameter must be determined for each load profile (Toronto, Winnipeg and Fredericton), but does not influence the solar, storage or evaporator operation. A set of preliminary simulations was made by iterating the condenser size (for space heat load) for a range of evaporator sizes and other parameters. In each case the same condenser value was the clear optimum. As the condenser was increased to this value, system solar fraction increased and solar cost decreased. Above this value, solar fraction remained constant (constrained by other system parameters) and solar cost increased slightly due to the higher condenser cost.

Another preliminary analysis was done to investigate the parameters for the tapwater load evaporator and condenser capacities. Again the condenser parameter can be set at an optimum independent of the solar/storage system parameter study. To reduce the analytic complexity, the evaporator parameter was also set at a constant value for a given system condition. The value selected provided a COP similar to the house

load heat pump, a reasonable evaporator delta T, and a flow rate which was significant but not out of proportion relative to the DHW load size. This compromise means that at high storage temeratures the DHW load extracts a relatively large volume of water compared to the volume injected and the volume extracted for the space heat evaporator. The system is thus not fully optimized but the basic results presented here are not expected to be very sensitive to this decision.

The selected parameter values for the space heat and tap water heat pump capacities are summarized in the following table. All values are in units of kilowatts per Kelvin (kW/K).

LOCATION	SPACE HEAT	TAPWATER	
	Cond	Evap	Cond
Toronto	200	30	40
Winnipeg	250	30	40
Fredericton	225	30	40

The heat pump evaporator heat transfer capacity (or flow rate) dramatically influences the performance of the solar/aquifer system for a given collector area and outlet temperature. This parameter must be carefully selected to provide maximum benefit from the capital investment in the collector array; otherwise the stored heat may not be fully or effectively recovered. Selection of the heat pump evaporator heat transfer capacity was done as part of the system optimization for each city.

MINREP runs for several combinations of collectors inlet/outlet temperature and collector size were made by varying the evaporator heat transfer capacity in the house heating system. The results of these runs, plotted as solar cost versus solar fraction, are contained in Figures 6.1 to 6.3. In some cases results were rejected because the volume of water extracted from storage exceeded the volume of water injected to storage.

The optimal system was defined as the 'knee' in the solar cost/solar fraction envelope. These systems were as follows:

	Collector Area (m^2)	Evaporator Size (kW/K)	Collector Outlet Temperature (C)	Solar Fraction (%)	Solar Cost ($/MWh)
Toronto	12500	200	15	68	52
Fredericton	15000	225	15	69	55
Winnipeg	15000	250	15	66	47

While the design of the optimal system varies, the solar fraction/solar cost values are approximately constant in the three cities at 68% and $51/MWh respectively.

These three optimal systems formed the basis of all further results in this report. Detailed MINSUN ouptut files for each of the three optimal systems are contained in Appendix B. Section 8.1 compares the three systems along with the Sub-task II(b) Base Case.

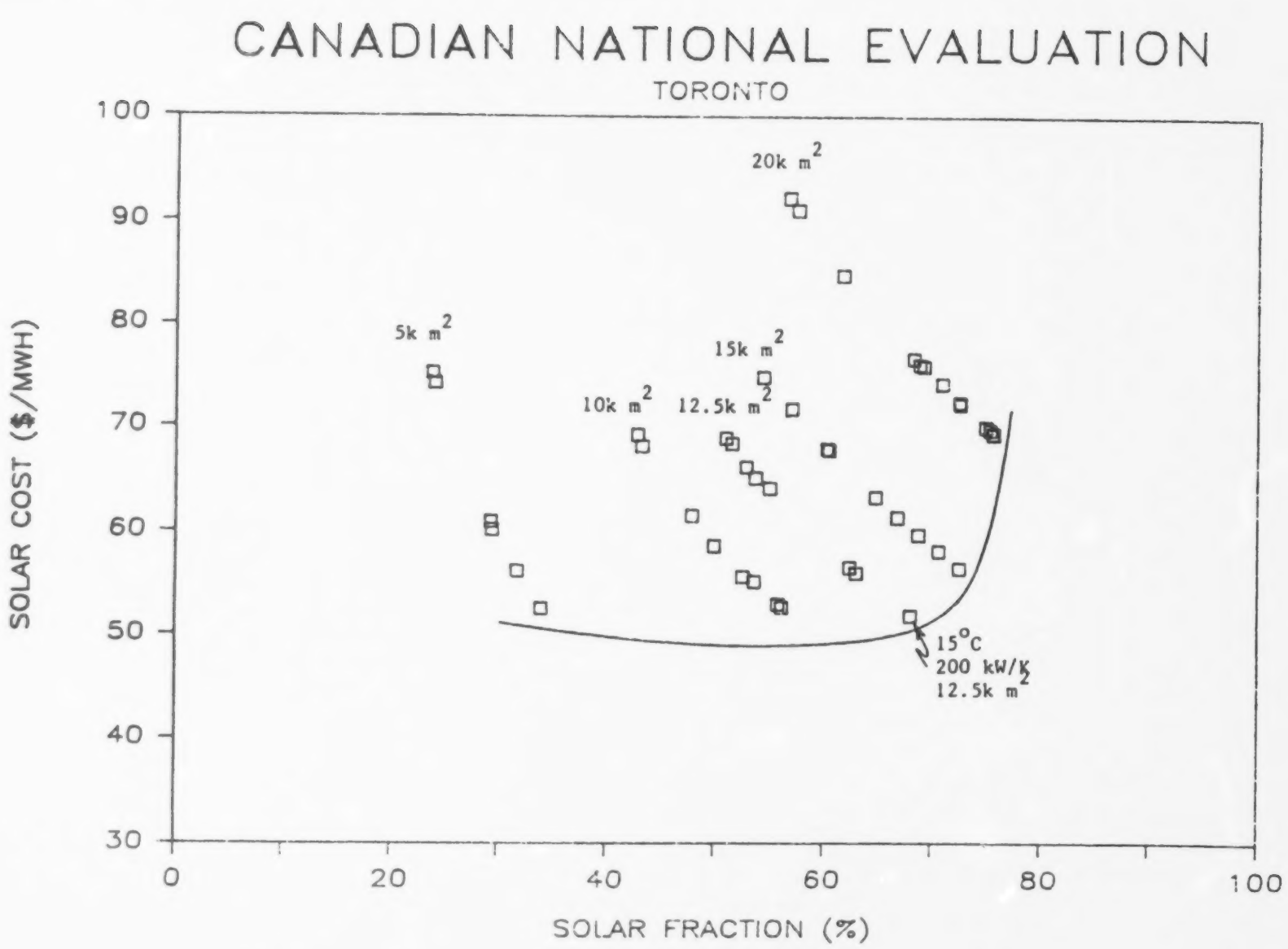

CANADIAN NATIONAL EVALUATION
TORONTO
SOLAR COST ($/MWH)
SOLAR FRACTION (%)
100
90
80
70
60
50
40
30
0
20
40
60
80
100
20k m2
5k m2
15k m2
10k m2
12.5k m2
15°C
200 kW/K
12.5k m2

FIGURE 6.1

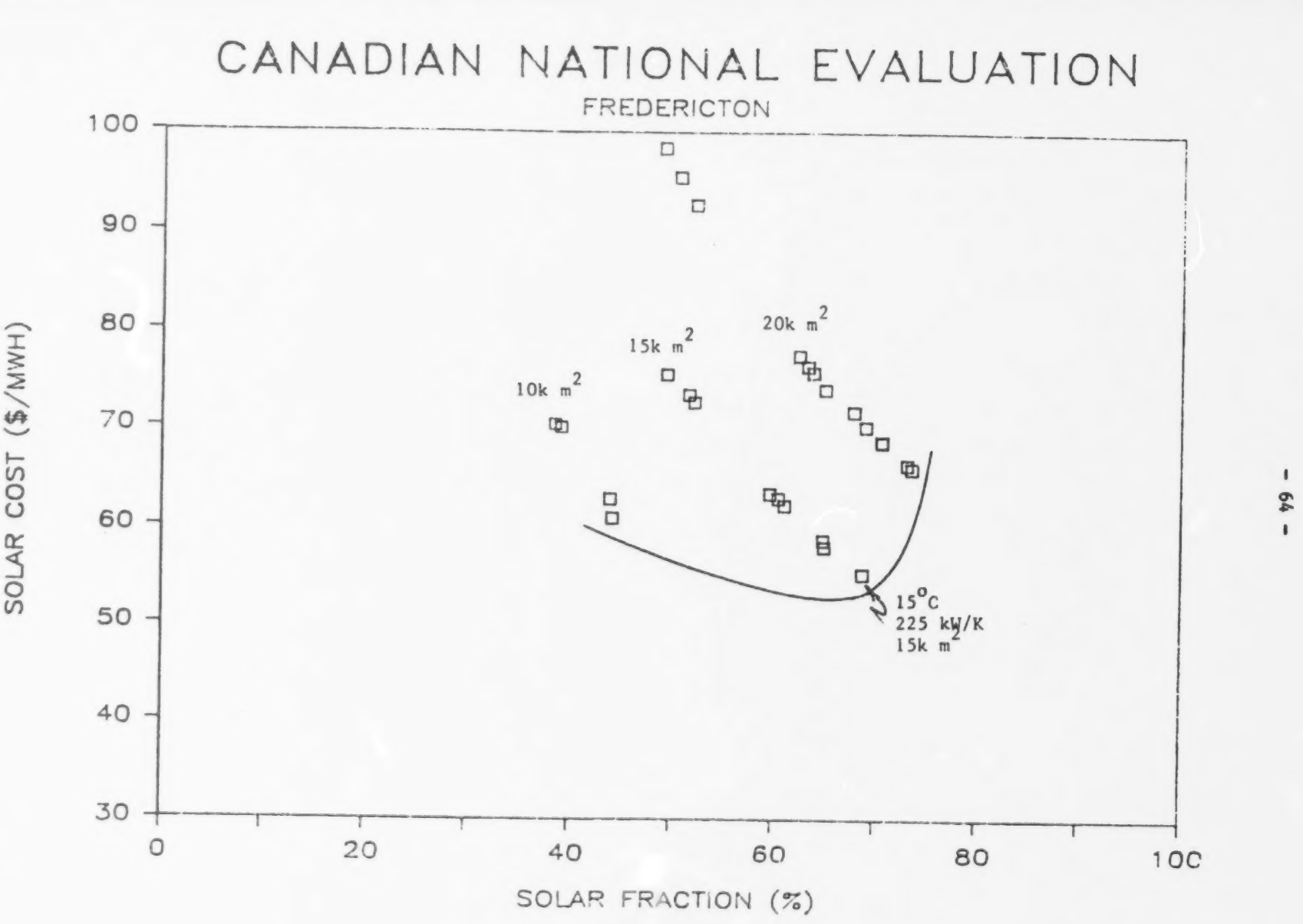

CANADIAN NATIONAL EVALUATION
FREDERICTON
SOLAR COST ($/MWH)
100
90
80
70
60
50
40
30
0
20
40
60
80
100
SOLAR FRACTION (%)
10k m2
15k m2
20k m2
15°C
225 kW/K
15k m2

FIGURE 6.2

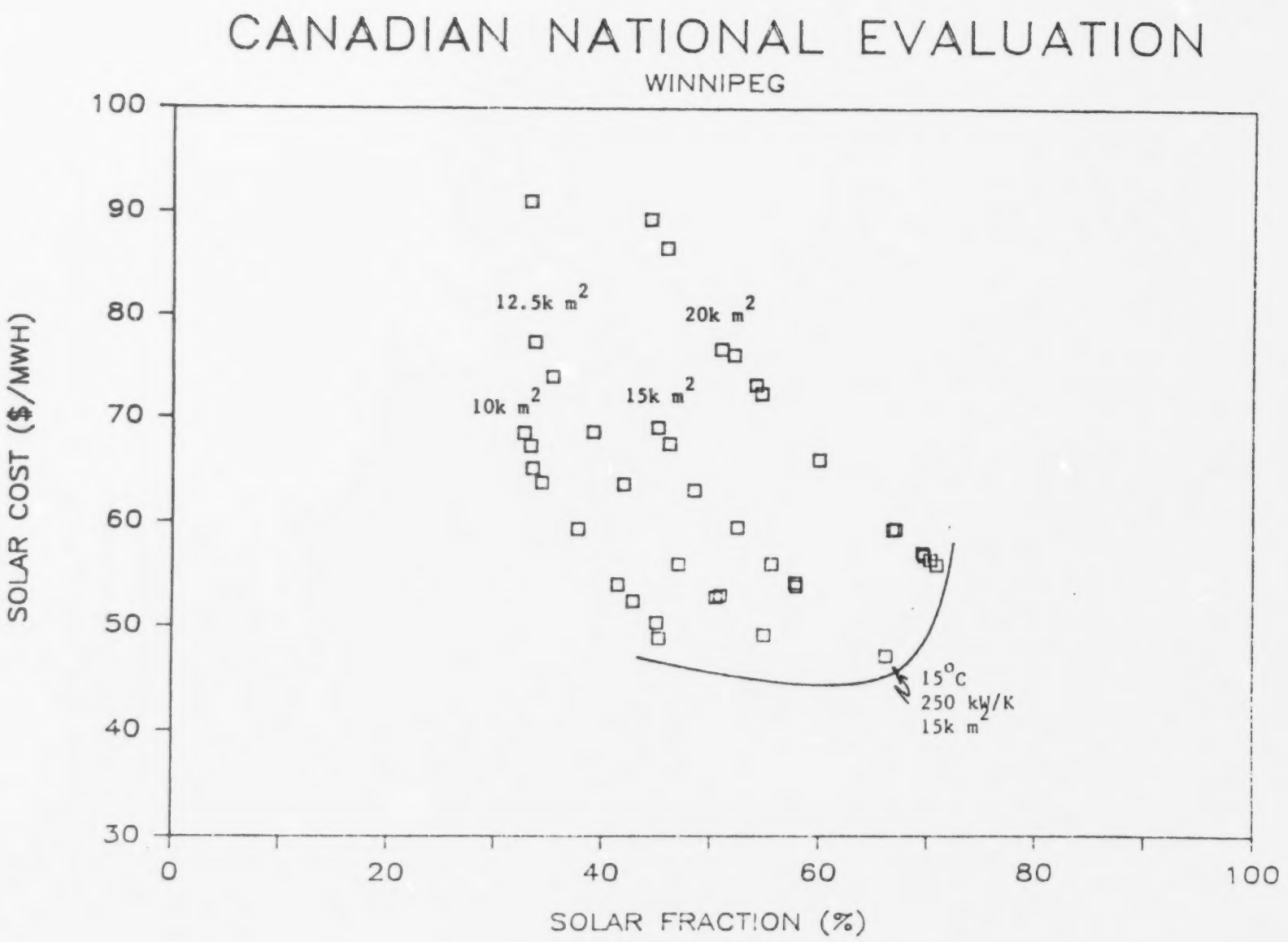

CANADIAN NATIONAL EVALUATION
WINNIPEG
SOLAR COST ($/MWH)
SOLAR FRACTION (%)
100
90
80
70
60
50
40
30
0
20
40
60
80
100
12.5k m2
20k m2
10k m2
15k m2
15°C
250 kW/K
15k m2

FIGURE 6.3

7.0 ECONOMIC ANALYSIS METHODOLOGY

The methodology adopted within Task VII for economic evaluation is the common present value analysis. In this methodology, costs in real, constant terms are estimated and projected over the life expectancy of a system, and the total present value of these costs is calculated using an appropriate discount rate. Since costs are expressed in real (constant) terms, the discount rate does not include an allowance for inflation. Some costs, such as for fuel, are projected to increase in real terms relative to other costs (commodities) and are said to have an escalation rate (of, say, two per cent per year).

The total present value of all costs, both capital and operating, can be expressed as a normalized annual cost which is constant over the life expectancy of the plant. This constant annual cost can be divided by the annual energy produced by the system to obtain a per unit energy cost from the system. This present value analysis methodology is useful and appropriate for the analytic work being performed in Phase II. More detailed capital investment and financial analyses would be required before detailed design and construction were considered.

Solar component capital cost includes:

- collector subsystem cost,
- storage subsystem cost,
- transmission pipe cost between collectors and storage,
- heat pump costs,

These capital costs are converted to a levelized annual cost by multiplying by the appropriate annualization factor dependent on life expectancy and discount rate. This is done by MINSUN. Operating costs, other than for fuel, are not identified separately in the current MINSUN code. They are, in effect, assumed to be included in the capital cost estimates. Auxiliary fuel costs are not included in solar cost nor are heat pump energy costs. The rationale for <u>including</u> heat pump capital

is that the solar system design is enhanced by having the heat pump in the system (collectors and storage operate at lower temperatures) and so this cost should be included in the solar component cost. The heat pump energy cost is excluded because this energy is delivered to the load (so is therefore not unlike auxiliary fuel cost) and the cost of this energy is dependent on assumptions about energy prices and location. The exclusion of the heat pump energy cost does not affect the daily operation of the heat pump system given the existing strategy. This strategy is such that load is always served directly from storage if the temperature is high enough and uses the heat pump when this storage temperature is too low for direct use by the load but high enough to allow the heat pump to function.

The solar component heat output is defined as that provided by the storage subsystem to the heat pump and to the load directly. Additional solar energy collected and stored but not used during the year is not counted.

In addition to the economic calculations performed within MINSUN, an extensive sensitivity analysis was performed separately for the three Canadian optimal systems (Toronto, Fredericton, and Winnipeg).

These calculations were performed outside of MINSUN with a microcomputer spreadsheet package using results from the MINSUN runs.

The following economic parameters were varied by factors from 0.5 to 1.5:

- discount rate
- fuel escalation rate
- depreciation time
- heatpump fuel cost
- auxiliary fuel cost

- collector cost
- aquifer cost
- heatpump cost
- piping cost
- auxiliary heater cost

The following results are recorded:

- total capital cost
- capital cost per house
- total levelized operating cost
- levelized operating cost per house
- total annualized system cost
- annualized system cost per house
- solar unit cost
- total unit cost at the central plant (excluding distribution costs)
- total unit cost including distribution
- unit cost without collectors
- capital cost without collectors
- annualized system cost without collectors.

Some results for Toronto are graphed.

8.0 RESULTS

8.1 OPTIMAL SYSTEM COMPARISON

The optimal systems for the three cities of the Canadian Application and the II(b) analysis city of Madison, are compared in Table 8.1. Costs for Madison are in American dollars, while costs for the other three cities are in Canadian dollars.

Figure 8.1 shows that energy incident on the collectors per unit area is greater in Winnipeg than Toronto or Fredericton, however the differences in collected energy per unit area are not as substantial. This is because heat loss from the collectors is greater in Winnipeg due to the lower average ambiant temperature.

Figure 8.2 illustrates the energy usage at the three sites. The total amount of solar radiation collected at each location is indicated by the line marked "solar collectors". All of this energy is stored in the aquifer. A portion of the energy marked "aquifer" is later retrieved to partially supply the load. When needed, the heat pump is used to upgrade the temperature of the water. The heat pump requires energy to operate, but this energy, marked "heat pump", is fully recovered to supply another portion of the load. Finally, "auxiliary" energy supplies the remaining part of the load. Thus, the sum of "auxiliary", "heat pump", and "aquifer" energy equals the "load". The difference between "solar collectors" and "aquifer" is the energy lost in the aquifer. The ratio between "aquifer" and "load" is equal to the solar fraction.

The load for Winnipeg is much greater than Toronto or Fredericton due to the more severe weather. This is met by a larger collector field which increases collected energy (marked "solar collectors"). The larger volumes of water and the resulting higher heat loss in the aquifer mean

that the heat pump is used more in Winnipeg. However, the portion of stored energy recovered and the auxiliary energy used is approximately the same for the three locations.

Figure 8.3 shows the component energy flows for Toronto on a weekly average basis over the simulation year. This illustrates the fluctuations which occur, even on a weekly basis, due to actual weather observations. Calculations within the program are made on a daily basis (for energy flow) and on an hourly basis (for collector performance).

Figure 8.4 illustrates the cost breakdown for the three Canadian locations. In terms of annualized cost per house (including distribution), this graph shows total cost as the sum of operating and capital costs. Capital costs are equal at Fredericton and Winnipeg, both greater than Toronto. This is because of the larger collector arrays required by the two cities. Operating costs clearly indicate the differences in fuel prices. Winnipeg, which uses the most energy, has the lowest fuel prices and as a result the lowest operating costs. Total cost is highest for Fredericton, followed by Winnipeg, and then Toronto.

TABLE 8.1: COMPARISON OF OPTIMAL CSHPSS SYSTEMS

		-----CANADIAN NATIONAL EVALUATION----			-II(b)-
		TORONTO	FREDERICTON	WINNIPEG	MADISON
LOAD:	HOUSES	500	500	500	500
	ENERGY (MWh/YR)	10047	10947	13524	10072
SOLAR COLLECTORS:	AREA (m**2)	12500	15000	15000	10000
	TEMPERATURE OUT (C)	15	15	15	15
	ENERGY:				
	INCIDENT (kWh/m**2 YR)	1446	1421	1662	--
	COLLECTED (MWh/YR)	8346	9619	10716	7336
	(kWh/m**2 YR)	668	641	714	734
AQUIFER:	THICKNESS (m)	20	20	20	20
	DEPTH BELOW GROUND (m)	20	20	20	20
	EXTRACTED ENERGY (MWh/YR)	6812	7526	8901	7205
	EFFICIENCY (%)	82	78	83	98
HEATPUMPS:	TAPWATER:				
	MAX COND POWER (MW)	0.3	0.3	0.3	0.23
	ELECTRIC ENERGY (MWh/YR)	559	561	591	497
	COP	4	4	3.8	3.9
	HOUSE HEAT:				
	MAX COND POWER (MW)	2.81	3.43	4.5	3.43
	ELECTRIC ENERGY (MWh/YR)	1794	2150	3342	1897
	COP	3.9	3.7	3.2	4.1
AUXILIARY:	TAPWATER:				
	MAX POWER (MW)	0.3	0.3	0.3	0.23
	ENERGY (MWh/YR)	385	404	406	77
	HOUSE HEAT:				
	MAX POWER (MW)	3	3.43	3.21	4.2
	ENERGY (MWh/YR)	498	307	284	397
SOLAR FRACTION (%)		68	69	66	72
SOLAR COST ($/MWh) (excludes distribution and energy costs)		52	55	47	31
CAPITAL COSTS:	SOLAR ($000)	3750	4500	4500	2450
	AQUIFER ($000)	250	250	250	154
	HEATPUMP ($000)	175	217	305	202
	AUXILIARY ($000)	300	364	321	420
	PIPING ($000)	2724	2724	2724	—
	TOTAL PER HOUSE ($000)	14.4	16.1	16.2	--
LEVELIZED OPERATING COSTS:					
	HEATPUMP ($000)	101	134	88	--
	AUXILIARY ($000)	21	20	13	--
ANNUALIZED SYSTEM COST ($000) (capital and operating)		673	770	720	—
	PER HOUSE ($)	1346	1540	1440	—

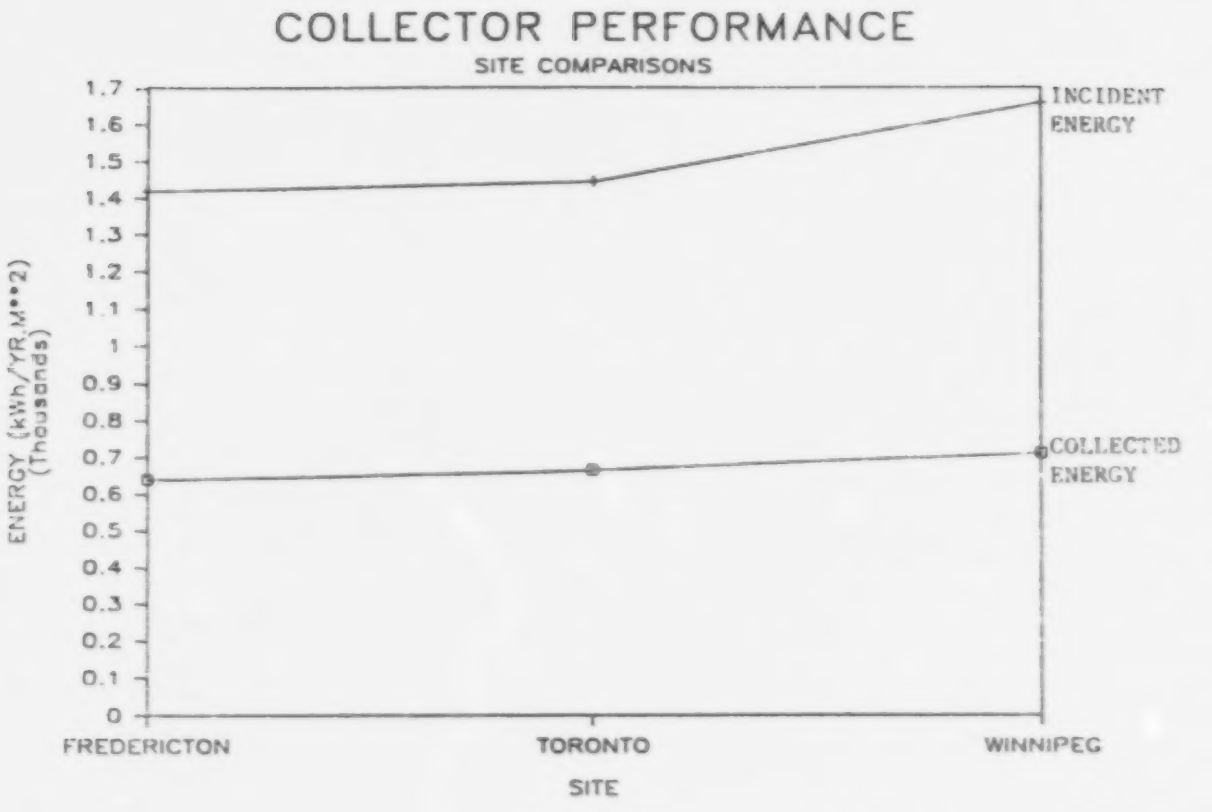


FIGURE 8.1

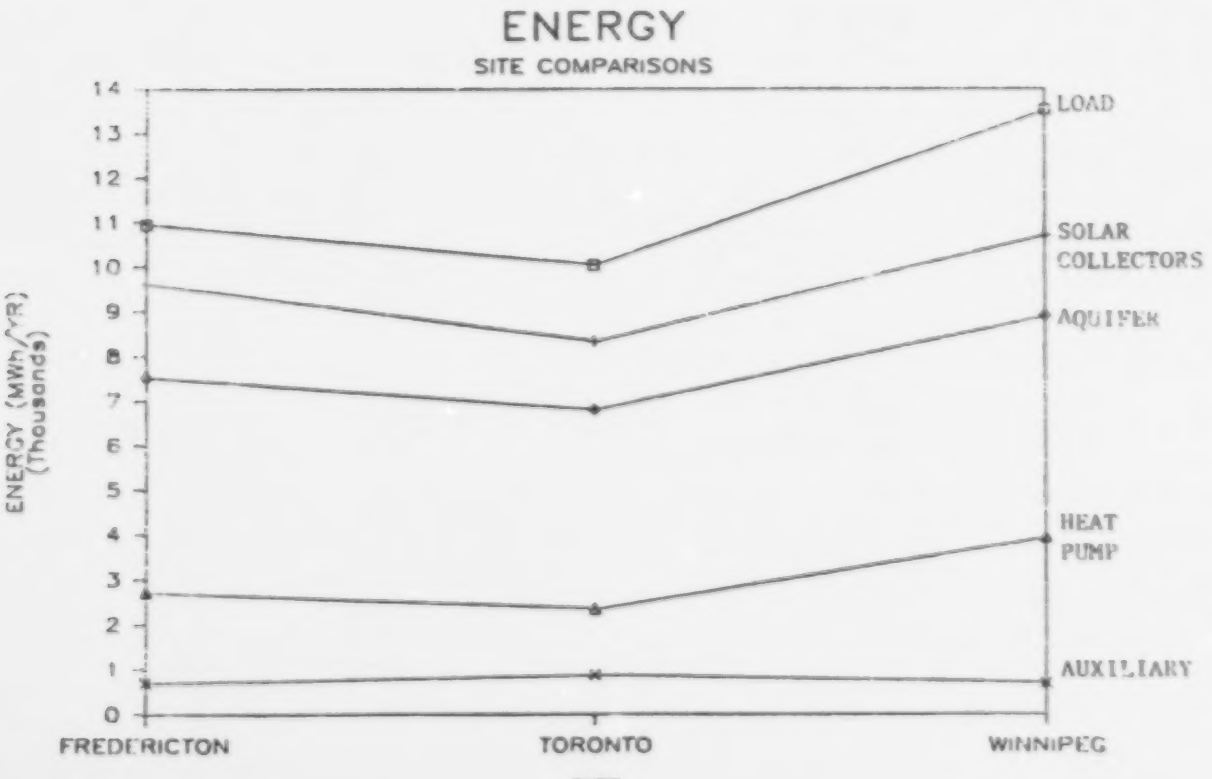


FIGURE 8.2

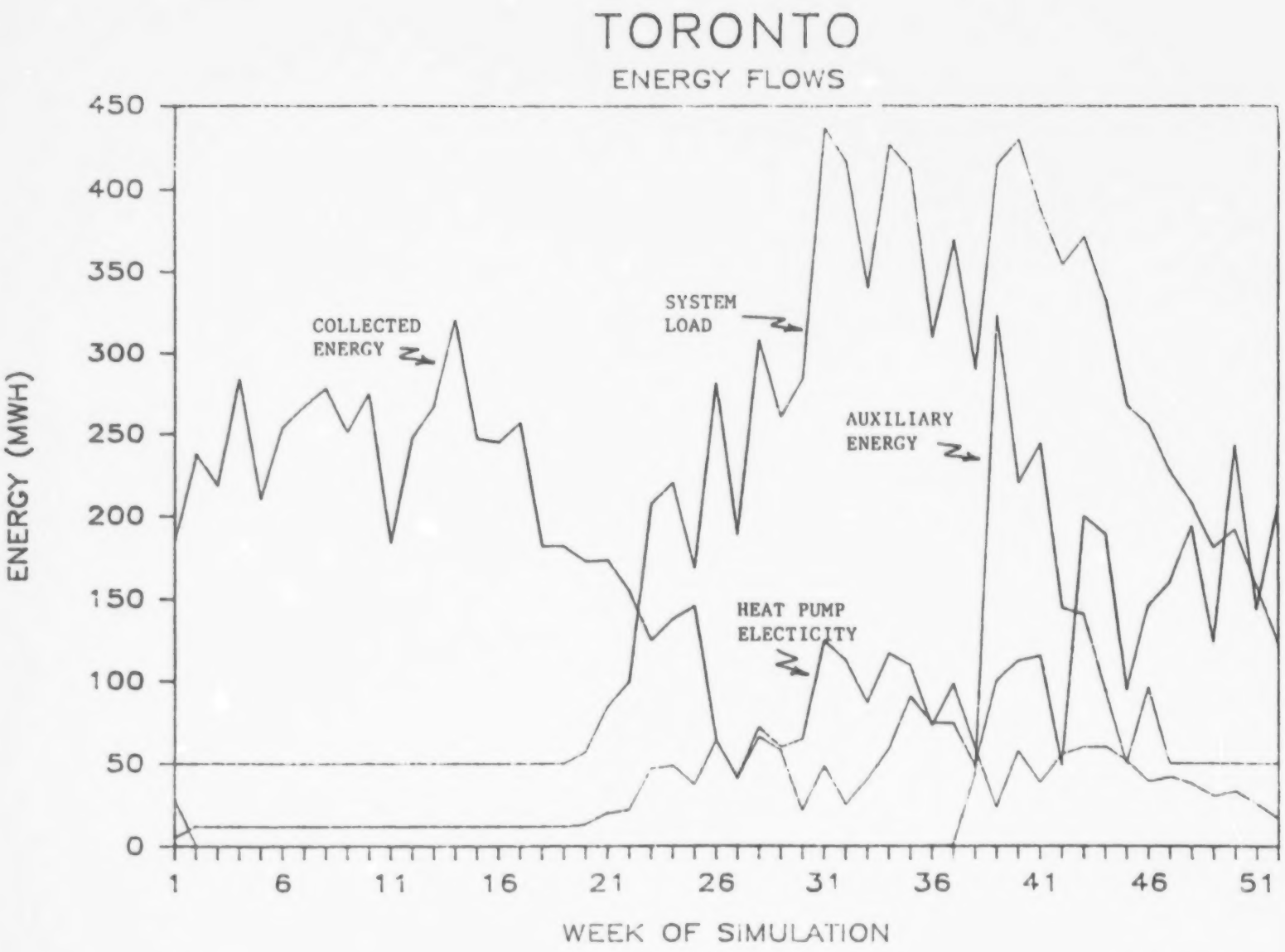

TORONTO
ENERGY FLOWS
ENERGY (MWH)
450
400
350
300
250
200
150
100
50
0
1
6
11
16
21
26
31
36
41
46
51
WEEK OF SIMULATION
COLLECTED ENERGY
SYSTEM LOAD
AUXILIARY ENERGY
HEAT PUMP ELECTICITY

FIGURE 8.3

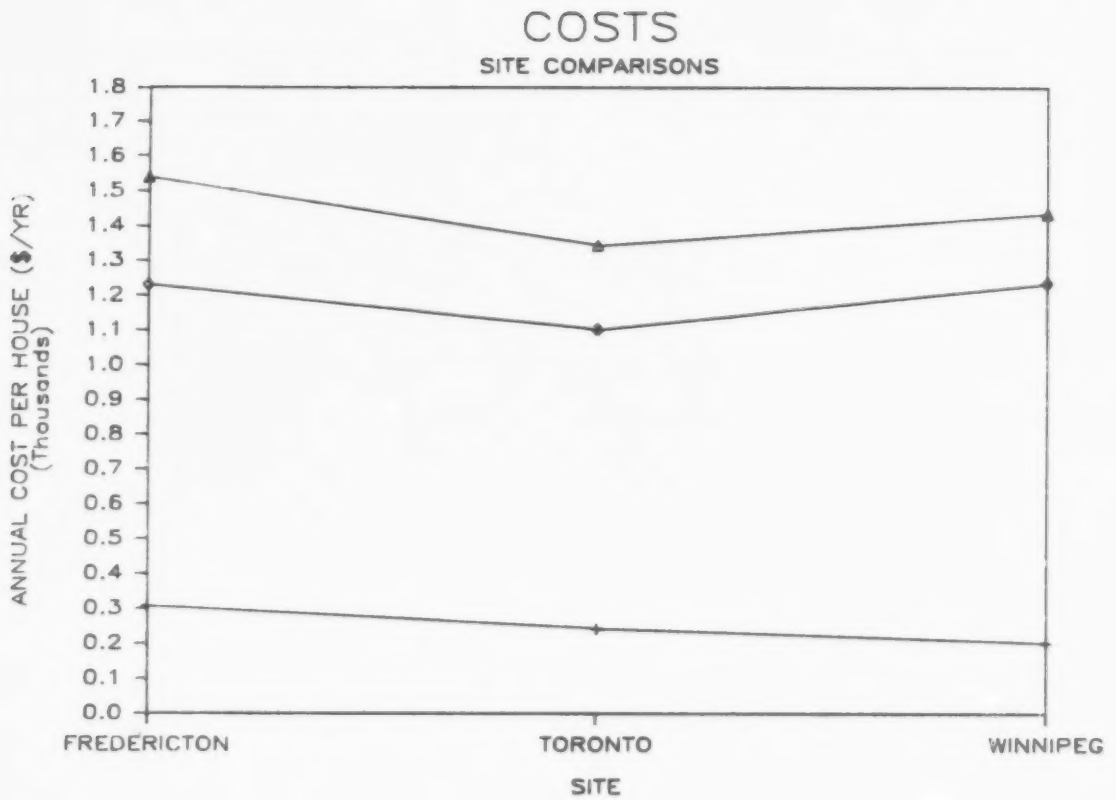

COSTS
SITE COMPARISONS
ANNUAL COST PER HOUSE ($/YR)
(Thousands)
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
FREDERICTON
TORONTO
WINNIPEG
SITE

Figure 8.4

8.2 ECONOMIC SENSITIVITY ANALYSIS

The economic factors of the three optimal systems were varied independently to ascertain their effect on various costs. The results are presented in Tables 8.2, 8.3, and 8.4. The results for the three locations are similar and so only the Toronto case is presented graphically.

Figures 8.5 to 8.8 show the effect of various economic factors on various unit costs. Solar unit cost includes only the capital cost of solar related items (collectors, aquifer, collector piping, heat pump) and is relative to the solar portion of load. Unit cost at CSHPSS includes operating costs and capital costs except the distribution system and is relative to the total load. Total unit cost includes all capital and operating costs and is relative to the total load.

The economic sensitivity analysis was based on a fixed system design. That is, the effect of varying a cost parameter was calculated as what the system cost would be as that cost parameter was varied but without re-optimizing the system design. Care must be taken in interpreting the results shown in the following tables and figures. For example, Figure 8.6, which shows unit costs as "heat pump fuel cost" (electricity) varies, shows that "solar unit cost" is less than "unit cost at CSHPSS" for electricity prices greater than 1.25 times the assumed base price. For this system design (which uses 2,352 MWh of electricity and 883 MWh of auxiliary energy plus solar to meet the load of 10,047 MWh) solar energy is less costly than that mix of electricity and auxiliary energy (when the electricity price is greater than 1.25 times base price). This design does not, however, produce thermal energy at less cost than the assumed cost of auxiliary energy (natural gas). As shown in Table 8.2, the assumed cost of auxiliary energy is about $20 per MWh or approximately 55% of the cost of the electricity.

Figure 8.9 breaks down total annual system cost per house into its component parts. The line 'COLLECTORS' represents the capital cost of collectors. The line 'SOLAR' represents the capital cost of solar related items (collectors, aquifer, collector piping and heat pump). The line 'AT CSHPSS' is the cost of generating the load requirement at the central heating plant, including capital and operating costs, but excluding distribution costs involved in bringing the energy to individual houses. 'TOfAL' is the total of all capital plus operating costs. Thus the difference between 'COLLECTORS' and 'SOLAR' is the capital cost of the aquifer, heat pump, and collector piping annualized per house. The difference between 'SOLAR' and 'AT CSHPSS' is the operating cost (fuel) plus the capital cost of the auxiliary heater annualized per house. The difference between 'AT CSHPSS' and 'TOTAL' is the capital cost of distribution piping annualized per house.

TABLE 8.2 (a)

ECONOMIC SENSITIVITY ANALYSIS FOR TORONTO

BASE PARAMETERS	CAPITAL COSTS		FUEL COSTS ($/MWh)		ECONOMIC PARAMETERS		ENERGY (MWh)	
	COLLECTORS	$3,750,000	AUXILIARY FUEL	$20.10	DEPRECIATION TIME	20	AUXILIARY ENERGY	882.62
	AQUIFER	$250,000	HEAT PUMP FUEL	$36.70	DISCOUNT RATE	5%	HEAT PUMP ENERGY	2352.41
	HEAT PUMP	$174,500			FUEL ESCALATION RATE	2%	STORAGE SUPPLY	6811.85
	COLLECTOR PIPING	$474,000					LOAD	10046.89
	DISTRIBUTION	$2,250,000					NUMBER OF HOUSES	500.00
	AUXILIARY HEATER	$300,000						

	FACTOR	PARAMETER VALUE	CAPITAL COST ANNUALIZATION FACTOR	OPERATING COST ANNUALIZATION FACTOR	CAPITAL COST TOTAL (INCL. DIST.)	CAPITAL COST PER HOUSE (INCL. DIST.)	LEVELIZED OPERATING COST ($/YR)	LEVELIZED OPERATING COST PER HOUSE	ANNUALIZED SYSTEM COST	ANNUALIZED SYSTEM COST PER HOUSE	SOLAR UNIT COST ($/MWh)	UNIT COST AT CSHPSS ($/MWh)	UNIT COST (INCL. DIST.) ($/MWh)	UNIT COST (INCL. DIST.) ($/MWh)	CAPITAL COST TOTAL (INCL. DIST.)	ANNUALIZED SYSTEM COST
									-SYSTEM COSTS WITHOUT COLLECTORS-							
	DISCOUNT RATE															
	0.60	3%	0.0653	1.1915	$7,198,500	$14,397	$124,006	$248	$593,765	$1,188	$44.53	$44.48	$59.10	$34.74	$3,448,500	$349,048
	0.80	4%	0.0708	1.1841	$7,198,500	$14,397	$123,229	$246	$632,535	$1,265	$48.28	$47.11	$62.96	$36.55	$3,448,500	$367,216
BASE	1.00	5%	0.0764	1.1768	$7,198,500	$14,397	$122,473	$245	$672,594	$1,345	$52.15	$49.83	$66.95	$38.42	$3,448,500	$386,013
	1.20	6%	0.0822	1.1697	$7,198,500	$14,397	$121,760	$243	$713,814	$1,428	$56.13	$52.63	$71.05	$40.35	$3,448,500	$405,378
	1.40	7%	0.0882	1.1629	$7,198,500	$14,397	$121,031	$242	$756,066	$1,512	$60.20	$55.50	$75.25	$42.33	$3,448,500	$425,249
	HEATPUMP FUEL COST															
	0.50	$18.35	0.0764	1.1768	$7,198,500	$14,397	$71,675	$143	$621,795	$1,244	$52.15	$44.77	$61.89	$33.37	$3,448,500	$335,215
	0.75	$27.53	0.0764	1.1768	$7,198,500	$14,397	$97,074	$194	$647,195	$1,294	$52.15	$47.30	$64.42	$35.89	$3,448,500	$360,614
BASE	1.00	$36.70	0.0764	1.1768	$7,198,500	$14,397	$122,473	$245	$672,594	$1,345	$52.15	$49.83	$66.95	$38.42	$3,448,500	$386,013
	1.25	$45.88	0.0764	1.1768	$7,198,500	$14,397	$147,872	$296	$697,993	$1,396	$52.15	$52.36	$69.47	$40.95	$3,448,500	$411,412
	1.50	$55.05	0.0764	1.1768	$7,198,500	$14,397	$173,272	$347	$723,392	$1,447	$52.15	$54.89	$72.00	$43.48	$3,448,500	$436,811
	AUXILIARY FUEL COST															
	0.50	$10.05	0.0764	1.1768	$7,198,500	$14,397	$112,035	$224	$662,155	$1,324	$52.15	$48.79	$65.91	$37.38	$3,448,500	$375,574
	0.75	$15.08	0.0764	1.1768	$7,198,500	$14,397	$117,254	$235	$667,374	$1,335	$52.15	$49.31	$66.43	$37.90	$3,448,500	$380,794
BASE	1.00	$20.10	0.0764	1.1768	$7,198,500	$14,397	$122,473	$245	$672,594	$1,345	$52.15	$49.83	$66.95	$38.42	$3,448,500	$386,013
	1.25	$25.13	0.0764	1.1768	$7,198,500	$14,397	$127,693	$255	$677,813	$1,356	$52.15	$50.35	$67.46	$38.94	$3,448,500	$391,232
	1.50	$30.15	0.0764	1.1768	$7,198,500	$14,397	$132,912	$266	$683,032	$1,366	$52.15	$50.87	$67.98	$39.46	$3,448,500	$396,451
	FUEL ESCALATION RATE															
	0.00	0%	0.0764	1.0000	$7,198,500	$14,397	$104,074	$208	$654,194	$1,308	$52.15	$48.00	$65.11	$36.59	$3,448,500	$367,614
	0.50	1%	0.0764	1.0835	$7,198,500	$14,397	$112,767	$226	$662,887	$1,326	$52.15	$48.86	$65.98	$37.45	$3,448,500	$376,306
BASE	1.00	2%	0.0764	1.1768	$7,198,500	$14,397	$122,473	$245	$672,594	$1,345	$52.15	$49.83	$66.95	$38.42	$3,448,500	$386,013
	1.50	3%	0.0764	1.2811	$7,198,500	$14,397	$133,325	$267	$683,445	$1,367	$52.15	$50.91	$68.03	$39.50	$3,448,500	$396,864
	2.00	4%	0.0764	1.3977	$7,198,500	$14,397	$145,468	$291	$695,588	$1,391	$52.15	$52.12	$69.23	$40.71	$3,448,500	$409,008
	DEPRECIATION TIME															
	0.50	$10	0.1233	1.0863	$7,198,500	$14,397	$113,056	$226	$1,000,902	$2,002	$84.17	$72.00	$99.62	$53.59	$3,448,500	$538,386
	0.75	$15	0.0918	1.1324	$7,198,500	$14,397	$117,852	$236	$778,348	$1,557	$62.61	$56.92	$77.47	$43.22	$3,448,500	$434,268
BASE	1.00	$20	0.0764	1.1768	$7,198,500	$14,397	$122,473	$245	$672,594	$1,345	$52.15	$49.83	$66.95	$38.42	$3,448,500	$386,013
	1.25	$25	0.0676	1.2193	$7,198,500	$14,397	$126,893	$254	$613,323	$1,227	$46.11	$45.91	$61.05	$35.82	$3,448,500	$359,921
	1.50	$30	0.0620	1.2596	$7,198,500	$14,397	$131,091	$262	$577,065	$1,154	$42.28	$43.56	$57.44	$34.31	$3,448,500	$344,739

TABLE 8.2 (b)

ECONOMIC SENSITIVITY ANALYSIS FOR TORONTO

BASE PARAMETERS

CAPITAL COSTS		FUEL COSTS ($/MWh)		ECONOMIC PARAMETERS		ENERGY (MWh)	
COLLECTORS	$3,750,000	AUXILIARY FUEL	$20.10	DEPRECIATION TIME	20	AUXILIARY ENERGY	882.62
AQUIFER	$250,000	HEAT PUMP FUEL	$36.70	DISCOUNT RATE	5%	HEAT PUMP ENERGY	2352.41
HEAT PUMP	$174,500			FUEL ESCALATION RATE	2%	STORAGE SUPPLY	6811.85
COLLECTOR PIPING	$474,000					LOAD	10046.89
DISTRIBUTION	$2,250,000					NUMBER OF HOUSES	500.00
AUXILIARY HEATER	$300,000						

	FACTOR	PARAMETER VALUE	CAPITAL COST ANNUALIZATION FACTOR	OPERATING COST ANNUALIZATION FACTOR	CAPITAL COST TOTAL (INCL. DIST.)	CAPITAL COST PER HOUSE (INCL. DIST.)	LEVELIZED OPERATING COST ($/YR)	LEVELIZED OPERATING COST PER HOUSE	ANNUALIZED SYSTEM COST	ANNUALIZED SYSTEM COST PER HOUSE	SOLAR UNIT COST ($/MWh)	UNIT COST AT CSHPSS ($/MWh)	UNIT COST (INCL. DIST.) ($/MWh)	UNIT COST (INCL. DIST.) ($/MWh)	CAPITAL COST TOTAL (INCL. DIST.)	ANNUALIZED SYSTEM COST
									-SYSTEM COSTS WITHOUT COLLECTORS-							
COLLECTOR COST																
	0.50	$1,875,000	0.0764	1.1768	$5,323,500	$10,647	$122,473	$245	$529,303	$1,059	$31.12	$35.57	$52.68	$38.42	$3,448,500	$386,013
	0.75	$2,812,500	0.0764	1.1768	$6,261,000	$12,522	$122,473	$245	$600,948	$1,202	$41.63	$42.70	$59.81	$38.42	$3,448,500	$386,013
BASE	1.00	$3,750,000	0.0764	1.1768	$7,198,500	$14,397	$122,473	$245	$672,594	$1,345	$52.15	$49.83	$66.95	$38.42	$3,448,500	$386,013
	1.25	$4,687,500	0.0764	1.1768	$8,136,000	$16,272	$122,473	$245	$744,239	$1,488	$62.67	$56.96	$74.08	$38.42	$3,448,500	$386,013
	1.50	$5,625,000	0.0764	1.1768	$9,073,500	$18,147	$122,473	$245	$815,884	$1,632	$73.19	$64.09	$81.21	$38.42	$3,448,500	$386,013
AQUIFER COST																
	0.50	$125,000	0.0764	1.1768	$7,073,500	$14,147	$122,473	$245	$663,041	$1,326	$50.75	$48.88	$65.99	$37.47	$3,323,500	$376,460
	0.75	$187,500	0.0764	1.1768	$7,136,000	$14,272	$122,473	$245	$667,817	$1,336	$51.45	$49.36	$66.47	$37.95	$3,386,000	$381,237
BASE	1.00	$250,000	0.0764	1.1768	$7,198,500	$14,397	$122,473	$245	$672,594	$1,345	$52.15	$49.83	$66.95	$38.42	$3,448,500	$386,013
	1.25	$312,500	0.0764	1.1768	$7,261,000	$14,522	$122,473	$245	$677,370	$1,355	$52.85	$50.31	$67.42	$38.90	$3,511,000	$390,789
	1.50	$375,000	0.0764	1.1768	$7,323,500	$14,647	$122,473	$245	$682,146	$1,364	$53.55	$50.78	$67.90	$39.37	$3,573,500	$395,566
HEATPUMP COST																
	0.50	$87,250	0.0764	1.1768	$7,111,250	$14,223	$122,473	$245	$665,926	$1,332	$51.17	$49.17	$66.28	$37.76	$3,361,250	$379,345
	0.75	$130,875	0.0764	1.1768	$7,154,875	$14,310	$122,473	$245	$669,260	$1,339	$51.66	$49.50	$66.61	$38.09	$3,404,875	$382,679
BASE	1.00	$174,500	0.0764	1.1768	$7,198,500	$14,397	$122,473	$245	$672,594	$1,345	$52.15	$49.83	$66.95	$38.42	$3,448,500	$386,013
	1.25	$218,125	0.0764	1.1768	$7,242,125	$14,484	$122,473	$245	$675,927	$1,352	$52.64	$50.16	$67.28	$38.75	$3,492,125	$389,347
	1.50	$261,750	0.0764	1.1768	$7,285,750	$14,572	$122,473	$245	$679,261	$1,359	$53.13	$50.49	$67.61	$39.08	$3,535,750	$392,681
PIPING COST																
	0.50	$1,362,000	0.0764	1.1768	$5,836,500	$11,673	$122,473	$245	$568,508	$1,137	$49.49	$48.03	$56.59	$28.06	$2,086,500	$281,927
	0.75	$2,043,000	0.0764	1.1768	$6,517,500	$13,035	$122,473	$245	$620,551	$1,241	$50.82	$48.93	$61.77	$33.24	$2,767,500	$333,970
BASE	1.00	$2,724,000	0.0764	1.1768	$7,198,500	$14,397	$122,473	$245	$672,594	$1,345	$52.15	$49.83	$66.95	$38.42	$3,448,500	$386,013
	1.25	$3,405,000	0.0764	1.1768	$7,879,500	$15,759	$122,473	$245	$724,637	$1,449	$53.48	$50.73	$72.13	$43.60	$4,129,500	$438,056
	1.50	$4,086,000	0.0764	1.1768	$8,560,500	$17,121	$122,473	$245	$776,680	$1,553	$54.81	$51.63	$77.31	$48.78	$4,810,500	$490,099
AUXILIARY HEATER COST																
	0.50	$150,000	0.0764	1.1768	$7,048,500	$14,097	$122,473	$245	$661,130	$1,322	$52.15	$48.69	$65.80	$37.28	$3,298,500	$374,550
	0.75	$225,000	0.0764	1.1768	$7,123,500	$14,247	$122,473	$245	$666,862	$1,334	$52.15	$49.26	$66.37	$37.85	$3,373,500	$380,281
BASE	1.00	$300,000	0.0764	1.1768	$7,198,500	$14,397	$122,473	$245	$672,594	$1,345	$52.15	$49.83	$66.95	$38.42	$3,448,500	$386,013
	1.25	$375,000	0.0764	1.1768	$7,273,500	$14,547	$122,473	$245	$678,325	$1,357	$52.15	$50.40	$67.52	$38.99	$3,523,500	$391,745
	1.50	$450,000	0.0764	1.1768	$7,348,500	$14,697	$122,473	$245	$684,057	$1,368	$52.15	$50.97	$68.09	$39.56	$3,598,500	$397,476

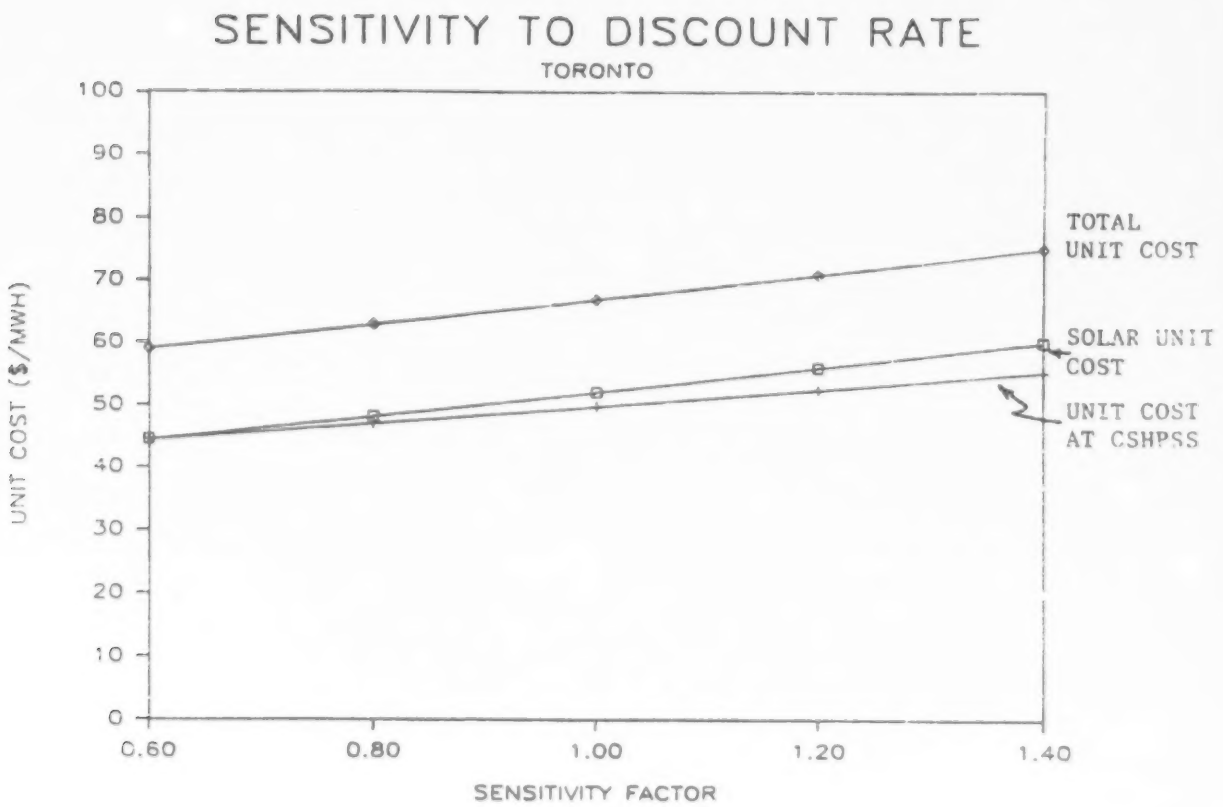


FIGURE 8.5

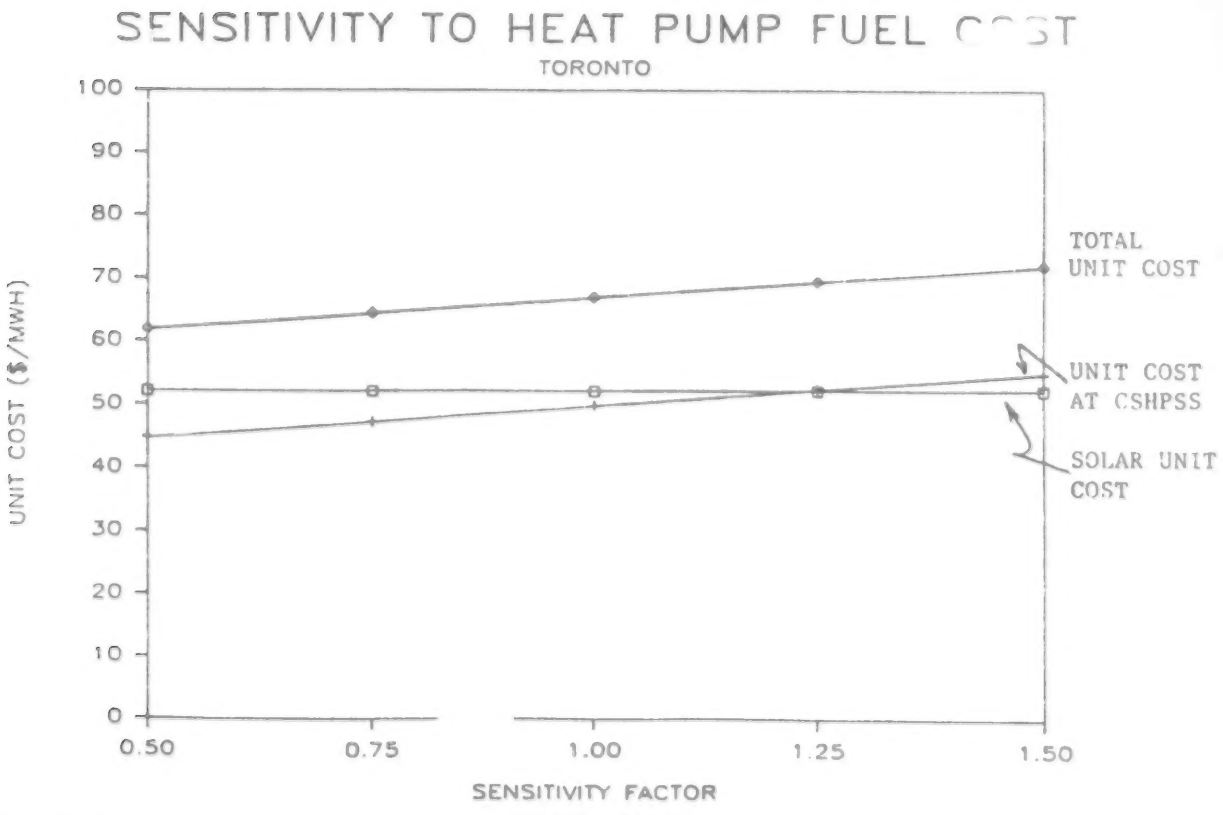


FIGURE 8.6

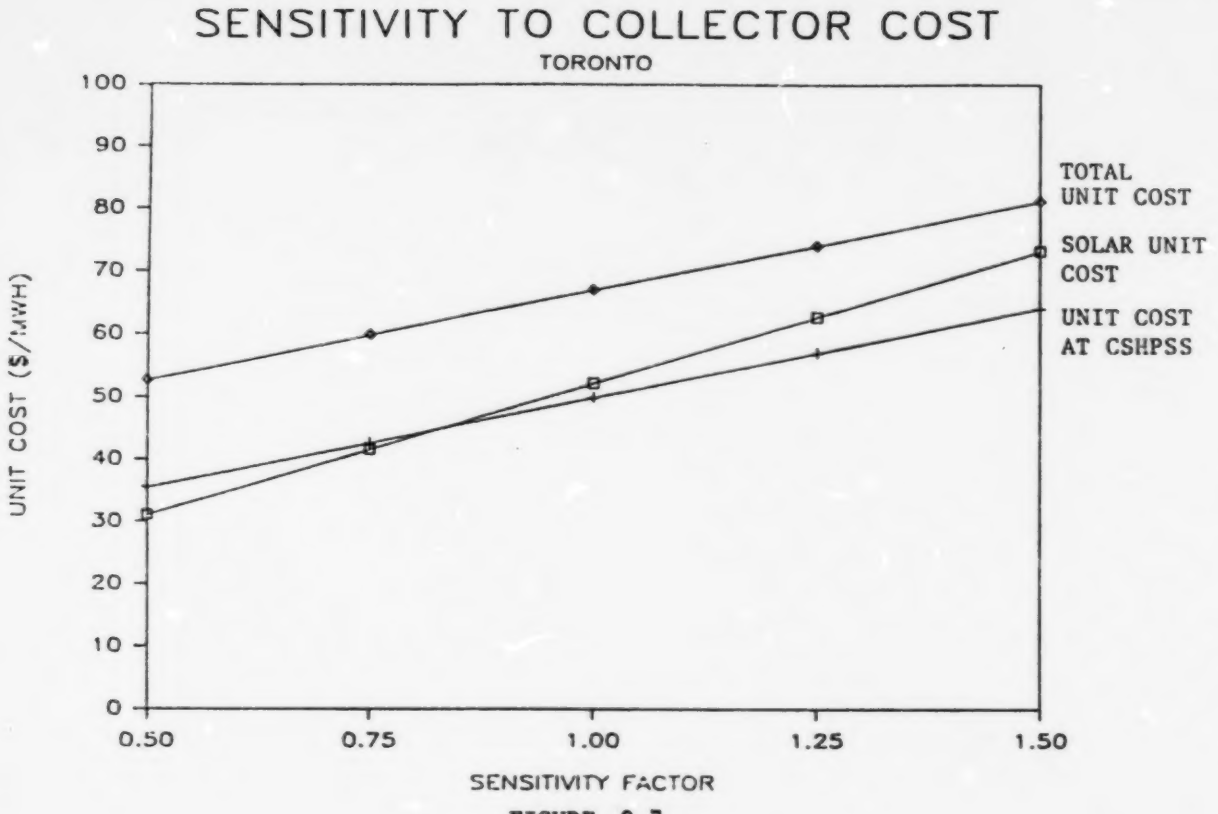


FIGURE 8.7

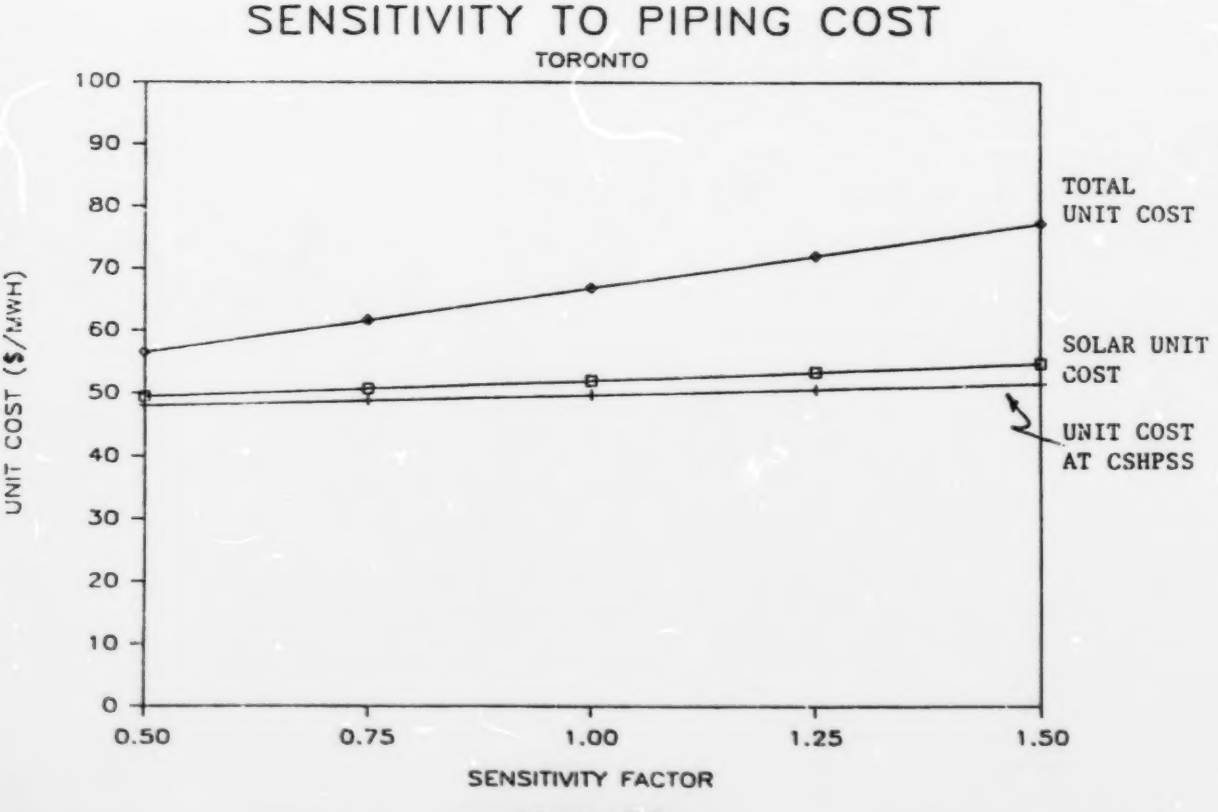


FIGURE 8.8

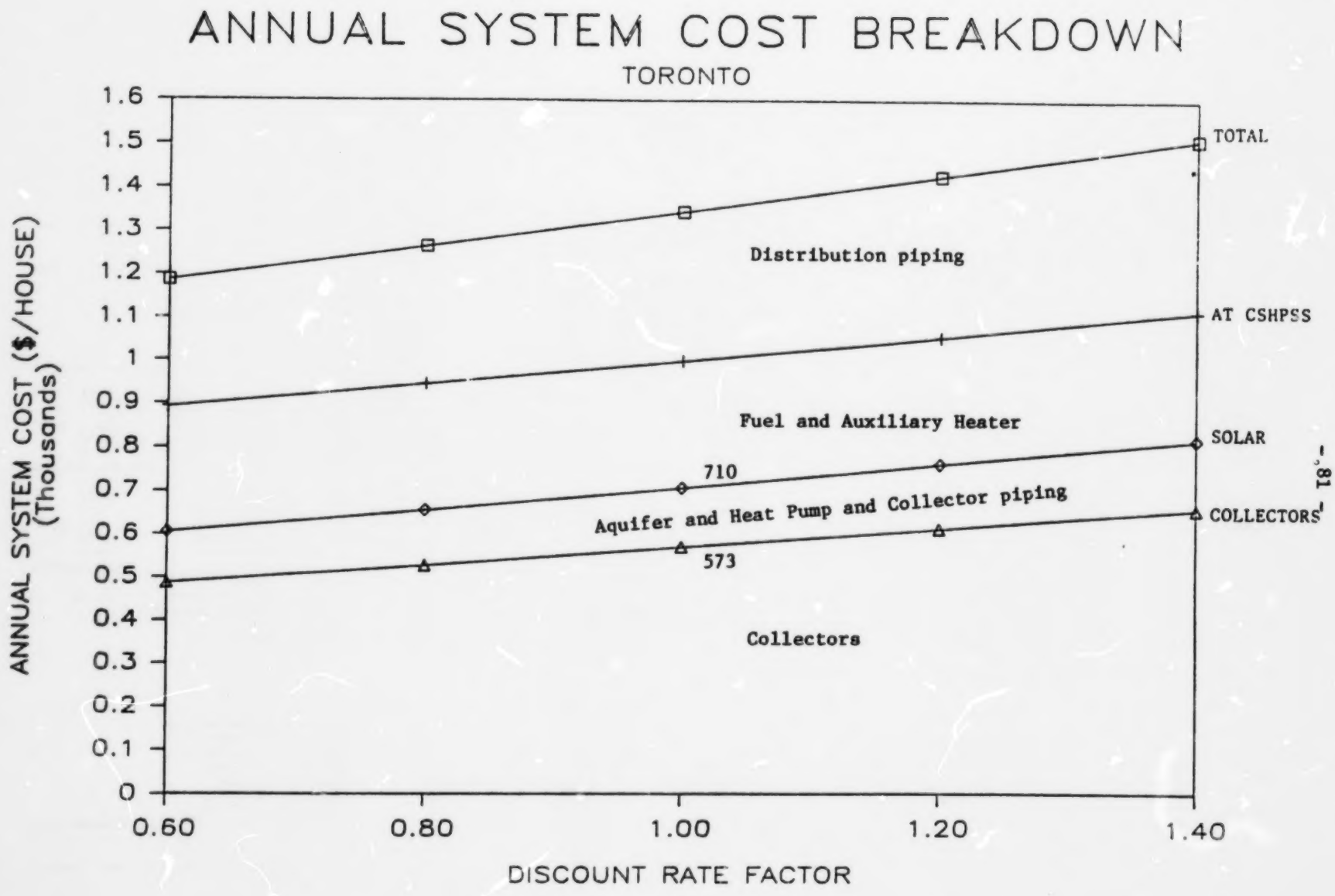

ANNUAL SYSTEM COST BREAKDOWN
TORONTO
ANNUAL SYSTEM COST ($/HOUSE) (Thousands)
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.60
0.80
1.00
1.20
1.40
DISCOUNT RATE FACTOR
TOTAL
Distribution piping
AT CSHPSS
Fuel and Auxiliary Heater
SOLAR
710
Aquifer and Heat Pump and Collector piping
COLLECTORS
573
Collectors
-81

FIGURE 8.9

TABLE 8.3 (a)

ECONOMIC SENSITIVITY ANALYSIS FOR FREDERICTON

BASE PARAMETERS

CAPITAL COSTS		FUEL COSTS ($/MWh)		ECONOMIC PARAMETERS		ENERGY (MWh)	
COLLECTORS	$4,500,000	AUXILIARY FUEL	$24.50	DEPRECIATION TIME	20	AUXILIARY ENERGY	710.91
AQUIFER	$250,000	HEAT PUMP FUEL	$42.10	DISCOUNT RATE	5%	HEAT PUMP ENERGY	2711.06
HEAT PUMP	$219,100			FUEL ESCALATION RATE	2%	STORAGE SUPPLY	7525.52
COLLECTOR PIPING	$474,000					LOAD	10947.49
DISTRIBUTION	$2,250,000					NUMBER OF HOUSES	500
AUXILIARY HEATER	$363,900						

	FACTOR	PARAMETER VALUE	CAPITAL COST ANNUALIZATION FACTOR	OPERATING COST ANNUALIZATION FACTOR	CAPITAL COST TOTAL (INCL. DIST.)	CAPITAL COST PER HOUSE (INCL. DIST.)	LEVELIZED OPERATING COST ($/YR)	LEVELIZED OPERATING COST PER HOUSE	ANNUALIZED SYSTEM COST	ANNUALIZED SYSTEM COST PER HOUSE	SOLAR UNIT COST ($/MWh)	UNIT COST AT CSHPSS ($/MWh)	UNIT COST (INCL. DIST.) ($/MWh)	-SYSTEM COSTS WITHOUT COLLECTORS- UNIT COST (INCL. DIST.) ($/MWh)	CAPITAL COST TOTAL (INCL. DIST.)	ANNUALIZED SYSTEM COST
DISCOUNT RATE																
	0.60	3%	0.0653	1.1915	$8,057,000	$16,114	$156,747	$313	$682,530	$1,365	$47.20	$48.93	$62.35	$35.52	$3,557,000	$388,870
	0.80	4%	0.0708	1.1841	$8,057,000	$16,114	$155,765	$312	$725,812	$1,452	$51.17	$51.76	$66.30	$37.22	$3,557,000	$407,429
BASE	1.00	5%	0.0764	1.1768	$8,057,000	$16,114	$154,810	$310	$770,538	$1,541	$55.27	$54.68	$70.38	$38.97	$3,557,000	$426,641
	1.20	6%	0.0822	1.1697	$8,057,000	$16,114	$153,883	$308	$816,568	$1,633	$59.49	$57.69	$74.59	$40.78	$3,557,000	$446,445
	1.40	7%	0.0882	1.1629	$8,057,000	$16,114	$152,986	$306	$863,756	$1,728	$63.81	$60.77	$78.90	$42.64	$3,557,000	$466,777
HEATPUMP FUEL COST																
	0.50	$21.05	0.0764	1.1768	$8,057,000	$16,114	$87,653	$175	$703,381	$1,407	$55.27	$48.54	$64.25	$32.84	$3,557,000	$359,485
	0.75	$31.58	0.0764	1.1768	$8,057,000	$16,114	$121,232	$242	$736,960	$1,474	$55.27	$51.61	$67.32	$35.90	$3,557,000	$393,063
BASE	1.00	$42.10	0.0764	1.1768	$8,057,000	$16,114	$154,810	$310	$770,538	$1,541	$55.27	$54.68	$70.38	$38.97	$3,557,000	$426,641
	1.25	$52.63	0.0764	1.1768	$8,057,000	$16,114	$188,389	$377	$804,117	$1,608	$55.27	$57.75	$73.45	$42.04	$3,557,000	$460,220
	1.50	$63.15	0.0764	1.1768	$8,057,000	$16,114	$221,967	$444	$837,695	$1,675	$55.27	$60.81	$76.52	$45.11	$3,557,000	$493,798
AUXILIARY FUEL COST																
	0.50	$12.25	0.0764	1.1768	$8,057,000	$16,114	$144,562	$289	$760,290	$1,521	$55.27	$53.74	$69.45	$38.04	$3,557,000	$416,393
	0.75	$18.38	0.0764	1.1768	$8,057,000	$16,114	$149,686	$299	$765,414	$1,531	$55.27	$54.21	$69.92	$38.50	$3,557,000	$421,517
BASE	1.00	$24.50	0.0764	1.1768	$8,057,000	$16,114	$154,810	$310	$770,538	$1,541	$55.27	$54.68	$70.38	$38.97	$3,557,000	$426,641
	1.25	$30.63	0.0764	1.1768	$8,057,000	$16,114	$159,934	$320	$775,662	$1,551	$55.27	$55.15	$70.85	$39.44	$3,557,000	$431,766
	1.50	$36.75	0.0764	1.1768	$8,057,000	$16,114	$165,058	$330	$780,786	$1,562	$55.27	$55.61	$71.32	$39.91	$3,557,000	$436,890
FUEL ESCALATION RATE																
	0.00	0%	0.0764	1.0000	$8,057,000	$16,114	$131,553	$263	$747,281	$1,495	$55.27	$52.55	$68.26	$36.85	$3,557,000	$403,384
	0.50	1%	0.0764	1.0835	$8,057,000	$16,114	$142,540	$285	$758,269	$1,517	$55.27	$53.56	$69.26	$37.85	$3,557,000	$414,372
BASE	1.00	2%	0.0764	1.1768	$8,057,000	$16,114	$154,810	$310	$770,538	$1,541	$55.27	$54.68	$70.38	$38.97	$3,557,000	$426,641
	1.50	3%	0.0764	1.2811	$8,057,000	$16,114	$168,527	$337	$784,255	$1,569	$55.27	$55.93	$71.64	$40.22	$3,557,000	$440,358
	2.00	4%	0.0764	1.3977	$8,057,000	$16,114	$183,876	$368	$799,604	$1,599	$55.27	$57.33	$73.04	$41.63	$3,557,000	$455,707
DEPRECIATION TIME																
	0.50	$10	0.1233	1.0863	$8,057,000	$16,114	$142,906	$286	$1,136,637	$2,273	$89.21	$78.48	$103.83	$53.13	$3,557,000	$581,618
	0.75	$15	0.0918	1.1324	$8,057,000	$16,114	$148,969	$298	$888,236	$1,776	$66.36	$62.28	$81.14	$43.42	$3,557,000	$475,340
BASE	1.00	$20	0.0764	1.1768	$8,057,000	$16,114	$154,810	$310	$770,538	$1,541	$55.27	$54.68	$70.38	$38.97	$3,557,000	$426,641
	1.25	$25	0.0676	1.2193	$8,057,000	$16,114	$160,397	$321	$704,839	$1,410	$48.88	$50.50	$64.38	$36.61	$3,557,000	$400,757
	1.50	$30	0.0620	1.2596	$8,057,000	$16,114	$165,703	$331	$664,865	$1,330	$44.81	$48.00	$60.73	$35.27	$3,557,000	$386,073

TABLE 8.3 (b)

ECONOMIC SENSITIVITY ANALYSIS FOR FREDERICTON

BASE PARAMETERS	CAPITAL COSTS		FUEL COSTS ($/MWh)		ECONOMIC PARAMETERS		ENERGY (MWh)	
	COLLECTORS	$4,500,000	AUXILIARY FUEL	$24.30	DEPRECIATION TIME	20	AUXILIARY ENERGY	710.91
	AQUIFER	$250,000	HEAT PUMP FUEL	$42.10	DISCOUNT RATE	5%	HEAT PUMP ENERGY	2711.06
	HEAT PUMP	$219,100			FUEL ESCALATION RATE	2%	STORAGE SUPPLY	7525.52
	COLLECTOR PIPING	$474,000					LOAD	10947.49
	DISTRIBUTION	$2,250,000					NUMBER OF HOUSES	500
	AUXILIARY HEATER	$363,900						

	FACTOR	PARAMETER VALUE	CAPITAL COST ANNUALIZATION FACTOR	OPERATING COST ANNUALIZATION FACTOR	CAPITAL COST TOTAL (INCL. DIST.)	CAPITAL COST PER HOUSE (INCL. DIST.)	LEVELIZED OPERATING COST ($/YR)	LEVELIZED OPERATING COST PER HOUSE	ANNUALIZED SYSTEM COST	ANNUALIZED SYSTEM COST PER HOUSE	SOLAR UNIT COST ($/MWh)	UNIT COST AT CSHPSS ($/MWh)	UNIT COST (INCL. DIST.) ($/MWh)	UNIT COST (INCL. DIST.) ($/MWh)	CAPITAL COST TOTAL (INCL. DIST.)	ANNUALIZED SYSTEM COST
											-SYSTEM COSTS WITHOUT COLLECTORS-					
COLLECTOR COST																
	0.50	$2,250,000	0.0764	1.1768	$5,807,000	$11,614	$154,810	$310	$598,590	$1,197	$32.43	$38.97	$54.68	$38.97	$3,557,000	$426,641
	0.75	$3,375,000	0.0764	1.1768	$6,932,000	$13,864	$154,810	$310	$684,564	$1,369	$43.85	$46.82	$62.53	$38.97	$3,557,000	$426,641
BASE	1.00	$4,500,000	0.0764	1.1768	$8,057,000	$16,114	$154,810	$310	$770,538	$1,541	$55.27	$54.68	$70.38	$38.97	$3,557,000	$426,641
	1.25	$5,625,000	0.0764	1.1768	$9,182,000	$18,364	$154,810	$310	$856,512	$1,713	$66.70	$62.53	$78.24	$38.97	$3,557,000	$426,641
	1.50	$6,750,000	0.0764	1.1768	$10,307,000	$20,614	$154,810	$310	$942,487	$1,885	$78.12	$70.38	$86.09	$38.97	$3,557,000	$426,641
AQUIFER COST																
	0.50	$125,000	0.0764	1.1768	$7,932,000	$15,864	$154,810	$310	$760,986	$1,522	$54.01	$53.81	$69.51	$38.10	$3,432,000	$417,089
	0.75	$187,500	0.0764	1.1768	$7,994,500	$15,989	$154,810	$310	$765,762	$1,532	$54.64	$54.24	$69.95	$38.54	$3,494,500	$421,865
BASE	1.00	$250,000	0.0764	1.1768	$8,057,000	$16,114	$154,810	$310	$770,538	$1,541	$55.27	$54.68	$70.38	$38.97	$3,557,000	$426,641
	1.25	$312,500	0.0764	1.1768	$8,119,500	$16,239	$154,810	$310	$775,315	$1,551	$55.91	$55.11	$70.82	$39.41	$3,619,500	$431,418
	1.50	$375,000	0.0764	1.1768	$8,182,000	$16,364	$154,810	$310	$780,091	$1,560	$56.54	$55.55	$71.26	$39.84	$3,682,000	$436,194
HEATPUMP COST																
	0.50	$109,550	0.0764	1.1768	$7,947,450	$15,895	$154,810	$310	$762,166	$1,524	$54.16	$53.91	$69.62	$38.21	$3,447,450	$418,269
	0.75	$164,325	0.0764	1.1768	$8,002,225	$16,004	$154,810	$310	$766,352	$1,533	$54.72	$54.30	$70.00	$38.59	$3,502,225	$422,455
BASE	1.00	$219,100	0.0764	1.1768	$8,057,000	$16,114	$154,810	$310	$770,538	$1,541	$55.27	$54.68	$70.38	$38.97	$3,557,000	$426,641
	1.25	$273,875	0.0764	1.1768	$8,111,775	$16,224	$154,810	$310	$774,724	$1,549	$55.83	$55.06	$70.77	$39.35	$3,611,775	$430,827
	1.50	$328,650	0.0764	1.1768	$8,166,550	$16,333	$154,810	$310	$778,910	$1,558	$56.39	$55.44	$71.15	$39.74	$3,666,550	$435,013
PIPING COST																
	0.50	$1,362,000	0.0764	1.1768	$6,695,000	$13,390	$154,810	$310	$666,452	$1,333	$52.87	$53.02	$60.88	$29.46	$2,195,000	$322,555
	0.75	$2,043,000	0.0764	1.1768	$7,376,000	$14,752	$154,810	$310	$718,495	$1,437	$54.07	$53.85	$65.63	$34.22	$2,876,000	$374,598
BASE	1.00	$2,724,000	0.0764	1.1768	$8,057,000	$16,114	$154,810	$310	$770,538	$1,541	$55.27	$54.68	$70.38	$38.97	$3,557,000	$426,641
	1.25	$3,405,000	0.0764	1.1768	$8,738,000	$17,476	$154,810	$310	$822,581	$1,645	$56.48	$55.51	$75.14	$43.73	$4,238,000	$478,684
	1.50	$4,086,000	0.0764	1.1768	$9,419,000	$18,838	$154,810	$310	$874,624	$1,749	$57.68	$56.33	$79.89	$48.48	$4,919,000	$530,728
AUXILIARY HEATER COST																
	0.50	$181,950	0.0764	1.1768	$7,875,050	$15,750	$154,810	$310	$756,633	$1,513	$55.27	$53.41	$69.11	$37.70	$3,375,050	$412,737
	0.75	$272,925	0.0764	1.1768	$7,966,025	$15,932	$154,810	$310	$763,586	$1,527	$55.27	$54.04	$69.75	$38.34	$3,466,025	$419,689
BASE	1.00	$363,900	0.0764	1.1768	$8,057,000	$16,114	$154,810	$310	$770,538	$1,541	$55.27	$54.68	$70.38	$38.97	$3,557,000	$426,641
	1.25	$454,875	0.0764	1.1768	$8,147,975	$16,296	$154,810	$310	$777,491	$1,555	$55.27	$55.31	$71.02	$39.61	$3,647,975	$433,594
	1.50	$545,850	0.0764	1.1768	$8,238,950	$16,478	$154,810	$310	$784,443	$1,569	$55.27	$55.95	$71.66	$40.24	$3,738,950	$440,546

TABLE 8.4 (a)

ECONOMIC SENSITIVITY ANALYSIS FOR WINNIPEG

BASE PARAMETERS	CAPITAL COSTS		FUEL COSTS ($/MWh)		ECONOMIC PARAMETERS		ENERGY (MWh)	
	COLLECTORS	$4,500,000	AUXILIARY FUEL	$15.90	DEPRECIATION TIME	20	AUXILIARY ENERGY	689.98
	AQUIFER	$250,000	HEAT PUMP FUEL	$19.00	DISCOUNT RATE	5%	HEAT PUMP ENERGY	3932.52
	HEAT PUMP	$304,800			FUEL ESCALATION RATE	2%	STORAGE SUPPLY	8901.32
	COLLECTOR PIPING	$474,000					LOAD	13523.82
	DISTRIBUTION	$2,250,000					NUMBER OF HOUSES	500.00
	AUXILIARY	$320,600						

	FACTOR	PARAMETER VALUE	CAPITAL COST ANNUAL-IZATION FACTOR	OPERATING COST ANNUAL-IZATION FACTOR	CAPITAL COST TOTAL (INCL. DIST.)	CAPITAL COST PER HOUSE (INCL. DIST.)	LEVELIZED OPERATING COST ($/YR)	LEVELIZED OPERATING COST PER HOUSE	ANNUALIZED SYSTEM COST	ANNUALIZED SYSTEM COST PER HOUSE	SOLAR UNIT COST ($/MWh)	UNIT COST AT CSHPSS ($/MWh)	UNIT COST (INCL. DIST.) ($/MWh)	UNIT COST (INCL. DIST.) ($/MWh)	CAPITAL COST TOTAL (INCL. DIST.)	ANNUALIZED SYSTEM COST
							-SYSTEM COSTS WITHOUT COLLECTORS-									
	DISCOUNT RATE															
	0.60	3%	0.0653	1.1915	$8,099,400	$16,199	$102,099	$204	$630,649	$1,261	$40.53	$35.78	$46.63	$24.92	$3,599,400	$336,989
	0.80	4%	0.0708	1.1841	$8,099,400	$16,199	$101,460	$203	$674,506	$1,349	$43.95	$38.10	$49.88	$26.33	$3,599,400	$356,123
BASE	1.00	5%	0.0764	1.1768	$8,099,400	$16,199	$100,837	$202	$719,806	$1,440	$47.47	$40.51	$53.23	$27.80	$3,599,400	$375,909
	1.20	6%	0.0822	1.1697	$8,099,400	$16,199	$100,234	$200	$766,406	$1,533	$51.09	$42.99	$56.67	$29.30	$3,599,400	$396,283
	1.40	7%	0.0882	1.1629	$8,099,400	$16,199	$99,649	$199	$814,160	$1,628	$54.79	$45.52	$60.20	$30.85	$3,599,400	$417,180
	HEATPUMP FUEL COST															
	0.50	$9.50	0.0764	1.1768	$8,099,400	$16,199	$56,874	$114	$675,842	$1,352	$47.47	$37.26	$49.97	$24.55	$3,599,400	$331,945
	0.75	$14.25	0.0764	1.1768	$8,099,400	$16,199	$78,856	$158	$697,824	$1,396	$47.47	$38.89	$51.60	$26.17	$3,599,400	$353,927
BASE	1.00	$19.00	0.0764	1.1768	$8,099,400	$16,199	$100,837	$202	$719,806	$1,440	$47.47	$40.51	$53.23	$27.80	$3,599,400	$375,909
	1.25	$23.75	0.0764	1.1768	$8,099,400	$16,199	$122,819	$246	$741,788	$1,484	$47.47	$42.14	$54.85	$29.42	$3,599,400	$397,891
	1.50	$28.50	0.0764	1.1768	$8,099,400	$16,199	$144,801	$290	$763,769	$1,528	$47.47	$43.76	$56.48	$31.05	$3,599,400	$419,873
	AUXILIARY FUEL COST															
	0.50	$7.95	0.0764	1.1768	$8,099,400	$16,199	$94,382	$189	$713,351	$1,427	$47.47	$40.03	$52.75	$27.32	$3,599,400	$369,454
	0.75	$11.93	0.0764	1.1768	$8,099,400	$16,199	$97,610	$195	$716,578	$1,433	$47.47	$40.27	$52.99	$27.56	$3,599,400	$372,681
BASE	1.00	$15.90	0.0764	1.1768	$8,099,400	$16,199	$100,837	$202	$719,806	$1,440	$47.47	$40.51	$53.23	$27.80	$3,599,400	$375,909
	1.25	$19.88	0.0764	1.1768	$8,099,400	$16,199	$104,065	$208	$723,033	$1,446	$47.47	$40.75	$53.46	$28.03	$3,599,400	$379,137
	1.50	$23.85	0.0764	1.1768	$8,099,400	$16,199	$107,293	$215	$726,261	$1,453	$47.47	$40.99	$53.70	$28.27	$3,599,400	$382,364
	FUEL ESCALATION RATE															
	0.00	0%	0.0764	1.0000	$8,099,400	$16,199	$85,689	$171	$704,657	$1,409	$47.47	$39.39	$52.10	$26.68	$3,599,400	$360,760
	0.50	1%	0.0764	1.0835	$8,099,400	$16,199	$92,845	$186	$711,814	$1,424	$47.47	$39.92	$52.63	$27.21	$3,599,400	$367,917
BASE	1.00	2%	0.0764	1.1768	$8,099,400	$16,199	$100,837	$202	$719,806	$1,440	$47.47	$40.51	$53.23	$27.80	$3,599,400	$375,909
	1.50	3%	0.0764	1.2811	$8,099,400	$16,199	$109,772	$220	$728,740	$1,457	$47.47	$41.17	$53.89	$28.46	$3,599,400	$384,843
	2.00	4%	0.0764	1.3977	$8,099,400	$16,199	$119,770	$240	$738,738	$1,477	$47.47	$41.91	$54.62	$29.20	$3,599,400	$394,842
	DEPRECIATION TIME															
	0.50	$10	0.1233	1.0863	$8,099,400	$16,199	$93,083	$186	$1,092,045	$2,184	$76.61	$60.23	$80.75	$39.71	$3,599,400	$537,025
	0.75	$15	0.0918	1.1324	$8,099,400	$16,199	$97,033	$194	$840,190	$1,680	$56.99	$46.86	$62.13	$31.60	$3,599,400	$427,294
BASE	1.00	$20	0.0764	1.1768	$8,099,400	$16,199	$100,837	$202	$719,806	$1,440	$47.47	$40.51	$53.23	$27.80	$3,599,400	$375,909
	1.25	$25	0.0676	1.2193	$8,099,400	$16,199	$104,476	$209	$651,783	$1,304	$41.97	$36.95	$48.20	$25.71	$3,599,400	$347,701
	1.50	$30	0.0620	1.2596	$8,099,400	$16,199	$107,933	$216	$609,721	$1,219	$38.48	$34.78	$45.08	$24.47	$3,599,400	$330,929

TABLE 8.4 (b)

ECONOMIC SENSITIVITY ANALYSIS FOR WINNIPEG

BASE PARAMETERS

CAPITAL COSTS		FUEL COSTS ($/MWh)		ECONOMIC PARAMETERS		ENERGY (MWh)	
COLLECTORS	$4,500,000	AUXILIARY FUEL	$15.90	DEPRECIATION TIME	20	AUXILIARY ENERGY	689.98
AQUIFER	$250,000	HEAT PUMP FUEL	$19.00	DISCOUNT RATE	5%	HEAT PUMP ENERGY	3932.52
HEAT PUMP	$304,800			FUEL ESCALATION RATE	2%	STORAGE SUPPLY	8901.32
COLLECTOR PIPING	$474,000					LOAD	13523.82
DISTRIBUTION	$2,250,000					NUMBER OF HOUSES	500.00
AUXILIARY	$320,600						

	FACTOR	PARAMETER VALUE	CAPITAL COST ANNUALIZATION FACTOR	OPERATING COST ANNUALIZATION FACTOR	CAPITAL COST TOTAL (INCL. DIST.)	CAPITAL COST PER HOUSE (INCL. DIST.)	LEVELIZED OPERATING COST ($/YR)	LEVELIZED OPERATING COST PER HOUSE	ANNUALIZED SYSTEM COST	ANNUALIZED SYSTEM COST PER HOUSE	SOLAR UNIT COST ($/MWh)	UNIT COST AT CSHPSS ($/MWh)	UNIT COST (INCL. DIST.) ($/MWh)	-SYSTEM COSTS WITHOUT COLLECTORS- UNIT COST (INCL. DIST.) ($/MWh)	CAPITAL COST TOTAL (INCL. DIST.)	ANNUALIZED SYSTEM COST
COLLECTOR COST																
	0.50	$2,250,000	0.0764	1.1768	$5,849,400	$11,699	$100,837	$202	$547,857	$1,096	$28.15	$27.80	$40.51	$27.80	$3,599,400	$375,909
	0.75	$3,375,000	0.0764	1.1768	$6,974,400	$13,949	$100,837	$202	$633,832	$1,268	$37.81	$34.15	$46.87	$27.80	$3,599,400	$375,909
BASE	1.00	$4,500,000	0.0764	1.1768	$8,099,400	$16,199	$100,837	$202	$719,806	$1,440	$47.47	$40.51	$53.23	$27.80	$3,599,400	$375,909
	1.25	$5,625,000	0.0764	1.1768	$9,224,400	$18,449	$100,837	$202	$805,780	$1,612	$57.13	$46.87	$59.58	$27.80	$3,599,400	$375,909
	1.50	$6,750,000	0.0764	1.1768	$10,349,400	$20,699	$100,837	$202	$891,754	$1,784	$66.78	$53.23	$65.94	$27.80	$3,599,400	$375,909
AQUIFER COST																
	0.50	$125,000	0.0764	1.1768	$7,974,400	$15,949	$100,837	$202	$710,253	$1,421	$46.39	$39.80	$52.52	$27.09	$3,474,400	$366,356
	0.75	$187,500	0.0764	1.1768	$8,036,900	$16,074	$100,837	$202	$715,029	$1,430	$46.93	$40.16	$52.87	$27.44	$3,536,900	$371,133
BASE	1.00	$250,000	0.0764	1.1768	$8,099,400	$16,199	$100,837	$202	$719,806	$1,440	$47.47	$40.51	$53.23	$27.80	$3,599,400	$375,909
	1.25	$312,500	0.0764	1.1768	$8,161,900	$16,324	$100,837	$202	$724,582	$1,449	$48.00	$40.86	$53.58	$28.15	$3,661,900	$380,685
	1.50	$375,000	0.0764	1.1768	$8,224,400	$16,449	$100,837	$202	$729,359	$1,459	$48.54	$41.22	$53.93	$28.50	$3,724,400	$385,462
HEATPUMP COST																
	0.50	$152,400	0.0764	1.1768	$7,947,000	$15,894	$100,837	$202	$708,159	$1,416	$46.16	$39.65	$52.36	$26.93	$3,447,000	$364,262
	0.75	$228,600	0.0764	1.1768	$8,023,200	$16,046	$100,837	$202	$713,982	$1,428	$46.81	$40.08	$52.79	$27.37	$3,523,200	$370,086
BASE	1.00	$304,800	0.0764	1.1768	$8,099,400	$16,199	$100,837	$202	$719,806	$1,440	$47.47	$40.51	$53.23	$27.80	$3,599,400	$375,909
	1.25	$381,000	0.0764	1.1768	$8,175,600	$16,351	$100,837	$202	$725,629	$1,451	$48.12	$40.94	$53.66	$28.23	$3,675,600	$381,732
	1.50	$457,200	0.0764	1.1768	$8,251,800	$16,504	$100,837	$202	$731,452	$1,463	$48.78	$41.37	$54.09	$28.66	$3,751,800	$387,556
PIPING COST																
	0.50	$1,362,000	0.0764	1.1768	$6,737,400	$13,475	$100,837	$202	$615,720	$1,231	$45.43	$39.17	$45.53	$20.10	$2,237,400	$271,823
	0.75	$2,043,000	0.0764	1.1768	$7,418,400	$14,837	$100,837	$202	$667,763	$1,336	$46.45	$39.84	$49.38	$23.95	$2,918,400	$323,866
BASE	1.00	$2,724,000	0.0764	1.1768	$8,099,400	$16,199	$100,837	$202	$719,806	$1,440	$47.47	$40.51	$53.23	$27.80	$3,599,400	$375,909
	1.25	$3,405,000	0.0764	1.1768	$8,780,400	$17,561	$100,837	$202	$771,849	$1,544	$48.48	$41.18	$57.07	$31.64	$4,280,400	$427,952
	1.50	$4,086,000	0.0764	1.1768	$9,461,400	$18,923	$100,837	$202	$823,892	$1,648	$49.50	$41.85	$60.92	$35.49	$4,961,400	$479,995
AUXILIARY HEATER COST																
	0.50	$160,300	0.0764	1.1768	$7,939,100	$15,878	$100,837	$202	$707,555	$1,415	$47.47	$39.60	$52.32	$26.89	$3,439,100	$363,659
	0.75	$240,450	0.0764	1.1768	$8,019,250	$16,039	$100,837	$202	$713,681	$1,427	$47.47	$40.06	$52.77	$27.34	$3,519,250	$369,784
BASE	1.00	$320,600	0.0764	1.1768	$8,099,400	$16,199	$100,837	$202	$719,806	$1,440	$47.47	$40.51	$53.23	$27.80	$3,599,400	$375,909
	1.25	$400,750	0.0764	1.1768	$8,179,550	$16,359	$100,837	$202	$725,931	$1,452	$47.47	$40.96	$53.68	$28.25	$3,679,550	$382,034
	1.50	$480,900	0.0764	1.1768	$8,259,700	$16,519	$100,837	$202	$732,056	$1,464	$47.47	$41.42	$54.13	$28.70	$3,759,700	$388,159

9.0 CONCLUSIONS

The objective of the overall Task VII exercise was to determine the technical feasibility and cost-effectiveness of solar/seasonal energy storage systems for large scale district heating. The more specific objectives of Sub-task II(b) were:

- to examine a wide range of CSHPSS configurations and load/location characteristics in order to compare and rank designs and applications, and
- to recommend configurations which deserve further attention for specific applications.

The results of the generic analyses of Sub-task II(b) together with the national evaluations of the participating countries address these objectives directly.

The generic analyses resulted in an assessment of ranking of system configurations based on parameters that are meaningful to all participating countries. These rankings are shown in Section 2 of this report. These rankings, together with an assessment of national conditions, provide the basis for selecting a specific configuration or configurations for re-analysis under national conditions. Only in the national context can the cost-effectivenes of such systems be properly assessed. This cost-effectiveness assessment must include the cost of available alternative sources for meeting the heating load.

In Canada, the current energy situation would favour applications where electricity could be substituted for fossil fuel sources. Given a source of even low temperature heat energy, this situation makes heat pump applications attractive for heating loads. Based on the Sub-task II(b) generic system results, the combination of heat pumps with aquifer

seasonal storage has good potential for meeting space heating demands with solar source. Central solar heating plants with seasonal storage (CSHPSS) using an aquifer and a heat pump were therefore selected for detailed analysis in this evaluation.

Although the total system costs using the CSHPSS concept are not directly competitive with alternative sources under today's price assumptions, cost advantages would exist:

- at low discount rates (below 3% real), or
- with a collector sub-system cost decrease of 20%.

These cost advantages are based on comparing the solar unit cost with the central plant unit cost using the specific design configuration and cost assumptions detailed in this report. This result is essentially based on the comparison of the solar source with electricity, rather than solar with the least cost alternative (fossil fuel). The delivered unit energy cost to the house, using the base parameters in this study, is approximately 6.7¢/kWh, which is up to double the cost of existing alternatives.

Besides the favourable results for solar source space heating applications indicated here, there are other system configurations that appear to be cost-effective under even today's energy price structure. Since the larger cost components of the configurations examined here are the solar collection field and the distribution system, cost-effectiveness would be significantly improved in a configuration with an alternate source of heat (waste heat recovery, e.g.) or with a concentrated load (without the need for a heat distribution system). Such applications of seasonal storage (the Scarborough Government of Canada Building, e.g.) are already under field trial in Canada and, in fact, form a significant contribution to this IEA Task.

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APPENDIX A

'BASE' MINSUN PARAMETER VALUES

MINSUN PARAMETER VALUES

PARAMETERS	
UMSORT	
Number of Days in each month J,F,M,A,M,J,J,A,S,O,N,D	31,28,31,30, 31,30,31,31, 30,31,30,31
Collector Type Flat Plate (includes Unglazed) Evacuated Tube (includes CPC)	0 or 1
Boes Model	
Madison	0
Copenhagen	0
Collector Product	
Flat Plate	0.808
CPC	0.700
Unglazed	0.90
Collector Linear Heat Loss Coefficient (W/m^2K)	
Flat Plate	4.4
CPC	1.000
Unglazed	15.000
Collector Quadratic Heat Loss Coefficient $(W/m^2K)^2$	
Flat Plate	0.000
CPC	0.000
Unglazed	0.000

PARAMETERS	
Incident Angle Modifier	
Flat Plate	0.100
CPC	0.050
Unglazed	0.100
Angle of Incline from Horizontal	
Flat Plate	Equal to Latitude
CPC	
Unglazed	
Direction (South = 0)	0
Reflectance of Diffuse Radiation	
Flat Plate	0.0
CPC	0.0
Unglazed	0.0
Latitude	
Madison	43
Copenhagen	56
Shift in Solar Time Hour Angle	0
Collector Inlet Temperatures (°C)	LT,NoHP 10, 30,50,70,90 LT,HP 5,20, 35,50,65 HT,NoHP 70, 90,110,130, 150 HT,HP 5, 20, 35, 50, 65
Outside temperature below which space heating is required (°C)	10
Desired Indoor Temperature (°C)	18

PARAMETERS	
ADVANCE	
Start Day Number	136
Number of Days	365
Array Effects	
Flat Plate	0.66
CPC	0.70
Unglazed	0.70

PARAMETERS	
MINSUN	
Options	Sing
	(Noheatp)
	(Tapw)
INSULATION	
Block	Insulation
Conductivity (W/mK)	0.04
Earth Temperature (°C)	10
Diameter Dependent Insulation Coefficient	0.1
Fixed Insulation Thickness (m)	0.02
COLLECTOR	
Block	Collectors
Option IEA = 3	3
Area (m^2)	Optimized
Temperature Step (not used in IEA)	N/A
Collector Temperature Control	
- Temperature Increase (°C)	0
- Temperature at which flow increases (°C)	Optimized
Dummy	N/A

PARAMETERS	
Max. Outlet Temperature (°C)	Equal to temperature at which flow increases
Minimum Flow ($kg/s/m^2$)	0.0001
Maximum Flow ($kg/s/m^2$)	0.1
Collector Network Length (m) (collectors to storage)	Load dependent 1Gwh 100 m 10Gwh 316 m 100Gwh 1000m
Insulation Thickness (not used)	N/A
Pipe Diameter (m)	Load dependent 1Gwh 0.2 m 10Gwh 0.3 m 100Gwh 0.4 m

PARAMETERS	
Aquifer Storage	
Height (m)	20
Radius (m)	100
Thermal Conductivity (W/mK)	
Horizontal	2.0
Vertical	2.75
Aquifer Heat Capacity (J/m3K)	2.5E6
Aquifer Supply Temperature (C)	Varied (see text)
Maximum Simulation Time (years)	2
Initial Ground Surface Temp. (C)	10
Vertical Temperature Gradiant (C/m)	0.0
Number of Layers Above	1

PARAMETERS	
Layer Thermal Conductivity (W/mK)	2.75
Layer Heat Capacity (J/m^3K)	1.5E6
Layer Thickness (m)	20
Number of Layers Below	1
Layer Thermal Conductivity (W/mK)	2.75
Layer Heat Capacity (J/m^3K)	3.1E6
Layer Thickness (m)	40
PERIOD	
First Day	274
Last Day	135
HOUSELOAD AND DISTRIBUTION	
Block	Houseload
Number of Houses	Load Dependent 1 GWh 10 GWh 100 GWh
Heat Loss Area (m^2)	350
K value (W/m^2K) Madison Copenhagen	 0.583 0.707
Indoor Temperature (°C)	18
Distribution Option 3 way 4 way	3
Distribution Control Option Return Temperature Fixed (1) Temperature Decrease Fixed (2)	1

PARAMETERS		
	HT	LT
Minimum Delivery Temperature (°C)	80	50
Slope Temperature Curve	1.75	0.5
Break Point Temperature (°C)	0	0
Return Temperature (°C)	60	30
Other Heat Sources (W/house)	400	
Tap Water Demand (average) (W)	%DHW dependent	
	0%	0
	20%	460
	50%	1825
Network Length (m)	0	
Distribution System Insulation Thickness (m)	0.1	
Distribution Pipe Diameter (m)	0.1	
HEAT PUMP	TAPW	HOUSE
Block	Heat pump	
Option		
Constant Flow (1)	1	1
Constant Temp. (2)		
HP efficiency	0.60	0.60
Break Point in efficiency curve (°C)	50	50
Stagnation Point in efficiency curve (°C)	100	100
Minimum Evap Outlet Temperature (°C)	5	5
Minimum COP	1.0	1.0
Evap Heat Transfer (kW/K) House	optimized	
Tapwater	10	20
Cond. Heat Transfer (kW/K) House	250(Madison) 200(Copenhagen)	
Tapwater	30	40
COST		
Block		

PARAMETERS		
Collector Cost Parameters (1980 US$/m^2)		
Flat Plate	245	
Advanced Evacuated Tube	350	
Unglazed	140	
Storage Cost Parameters (1980 US$)		
Well cost ($/m)	100	
Depth Cost Exponent	1	
Number of Wells	1	
Number of Wells Expontent	1	
Reference Flow Rate (m^2/5)	0.03	
Well Flow Exponent	0	
Equipment Cost	150,000	
Equipment Flow Exponent	0	
Ground Surface Area (m^2)	0	
Ground Cost ($/m^2)	0	
	LT	HT
Cost of Condenser ($/WK)	0.2	0.3
Cost of Evaporator ($/WK)	0.2	0.3
Cost of HP Motor ($/kW)	0.2	0.3
Reference Condensor Power (MW)	0.6	
Scale Factor for HP Costs	-0.3	
Specific Pipe Cost ($/m^2) (diameter dependent)	0.0	
Linear Pipe Cost ($/m)	250	

PARAMETERS	
Insulation Cost (included above)	0
Aux. Heat ($/W) (Capacity Cost)	0.1
Aux. Heat Cost ($/kWh)	0.07
HP Energy Cost ($/kWh)	0.07
Amortization Period (Years)	20
Discounting Rate (real) (% per annum)	5
Fuel Escalation Rate (real) (% per annum)	2

APPENDIX B

Detailed Results

- UMSORT output
- MINSUM output

For

Toronto
Fredericton
Winnipeg

optimal systems

```
 IEA DATA PROGRAM VERSION 1
  MONTH END DAYS  31  28  31  30  31  30  31  31  30  31  30  31
  COLLECTOR SWITCHES 1=ON,0=OFF

   FLAT PLATE=1 SALT POND=0 EVAC TUBE=0
   CENTRAL RECV=0 PARB TROUGH=0 SHAL POND=0
  BOES MODEL=1
     ALPHA         UL1          UL2       BO          TILT         DIR          RHO
 0.7530E 00   0.5250E 01       0.0000   0.1000E 00  0.4380E 02       0.0000   0.2000E 00
 0.3370E 00   0.2900E 00       0.0000   0.5000E-01       0.0000       0.0000        0.0000
 0.5100E 00   0.1310E 01       0.0000   0.1700E 00  0.4380E 02       0.0000   0.2000E 00
 0.9800E 00        0.0000      0.0000        0.0000       0.0000       0.0000        0.0000
 0.8070E 00   0.8900E-01   0.8690E 00        0.0000       0.0000       0.0000   0.2000E 00
 0.6400E 00   0.4400E 01       0.0000        0.0000       0.0000       0.0000        0.0000
LAT=43.80 LONG= 0.00 TEMPS= 10. 25. 40. 55. 70.
TAMB=10.  TROOM=18.
```

* IEA * UMSORT OUTPUT SUMMARY *

FOR COLLECTOR NUMBER : 1
FOR LOCATION :TORO

- TEMPERATURES IN DEGREES CELCIUS
- ALL ENERGIES IN MEGAJOULES/MONTH OR YEAR

MONTH	J	F	M	A	M	J	J	A	S	O	N	D	YEAR
AMB. TEMPERATURE	-5.8	-6.9	-2.2	5.8	10.9	17.7	21.0	20.0	15.6	8.5	2.7	-3.9	7.0
TEMP. FOR LOAD MOD	-5.8	-6.9	-2.2	6.8	12.6	16.9	18.0	18.0	15.9	10.0	3.3	-3.7	6.9
DIRECT NORMAL RAD.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
TOTAL HORIZONTAL	162.	225.	393.	472.	553.	662.	633.	618.	430.	286.	147.	115.	4696.
TOTAL INCIDENT	280.	353.	493.	492.	508.	582.	569.	616.	488.	399.	227.	197.	5205.
COLLECTED AT 10.	143.	179.	293.	333.	376.	484.	495.	526.	405.	289.	141.	96.	3761.
COLLECTED AT 25.	102.	131.	227.	256.	280.	373.	383.	418.	312.	214.	101.	65.	2861.
COLLECTED AT 40.	71.	96.	173.	197.	211.	289.	291.	332.	236.	158.	73.	42.	2168.
COLLECTED AT 55.	46.	67.	128.	152.	156.	218.	215.	255.	175.	112.	50.	24.	1598.
COLLECTED AT 70.	27.	44.	91.	112.	110.	159.	154.	193.	123.	74.	32.	12.	1133.
OP. HOURS AT 10.	173.	206.	265.	326.	401.	418.	413.	391.	350.	303.	192.	142.	3580.
OP. HOURS AT 25.	125.	143.	211.	229.	274.	346.	363.	345.	294.	223.	107.	89.	2749.
OP. HOURS AT 40.	100.	109.	170.	185.	218.	267.	291.	284.	241.	178.	90.	69.	2202.
OP. HOURS AT 55.	82.	90.	145.	145.	178.	228.	243.	243.	197.	146.	73.	51.	1821.
OP. HOURS AT 70.	55.	69.	117.	136.	145.	189.	192.	204.	171.	111.	50.	35.	1474.

IEA SOLAR HEATING PROGRAMME TASK VII : INTERSEASONAL STORAGE OF SOLAR ENERGY. OUTPUT FROM MINSUN (VERSION 4 DATE 83-11-29)

RUN TITLE : CANADIAN NATIONAL EVALUATION WITH AQUIFER STORAGE

S U M M A R Y O F I N P U T D A T A .

STORAGE OPTION SELECTED :

AQUIFER STORAGE MODEL (LUND)

W E A T H E R D A T A D E T A I L S

IEA MODEL - DATA PRE-PROCESSED BY PROGRAM UMSORT

TITLE CARD (CITY AND COLLECTOR TYPE) : TORO BOES FLAT PLAT

WEATHER DATA FILE HAS BEEN READ.

LAST DATE READ WAS	135	INDOOR TEMPERATURE (C)	18.0
HEATING IF AMBIENT TEMP. LESS THAN (C)	10.0		

RUN OPTIONS SELECTED FOR THIS RUN :

SINGULAR POINT CALCULATION
SEPARATE TAP WATER SYSTEM

I N S U L A T I O N D A T A

COLLECTOR PIPE INSULATION CONDUCTIVITY (W/MK)	0.040	EARTH TEMPERATURE (C)	10.00
DIAMETER DEPENDENT INSULATION THICKNESS (M/M)	0.100	FIXED INSULATION THICKNESS (M)	0.020

C O L L E C T O R D A T A (CENTRAL MOUNTED)

OPTION (MUST BE 3.)	3.	COLLECTOR AREA (SQ.M)	12500.0
MAX. (COLL. OUTLET - TOP STORAGE TEMP.) (C)	0.0	OUTLET TEMP. AT WHICH FLOW IS INCREASED (C)	15.0
MAXIMUM COLLECTOR OUTLET TEMPERATURE (C)	15.0		
NORMAL FLOW RATE (KG / S SQ.M)	0.0001	MAXIMUM FLOW RATE (KG / S SQ.M)	0.0200
COLLECTOR PIPING NETWORK LENGTH (M)	316.0	INSULATION THICKNESS (M)	0.000
PIPE DIAMETER (M)	0.400		

STORAGE DATA (AQUIFER STORAGE MODEL)

HEIGHT OF AQUIFER (M)	20.0	THERMAL RADIUS (M)	200.00
HORIZONTAL THERMAL CONDUCTIVITY (W/MK)	2.000	VERTICAL THERMAL CONDUCTIVITY (W/MK)	2.750
HEAT CAPACITY IN AQUIFER (J/M3K)	2499999.0	AQUIFER SUPPLY TEMPERATURE (C)	8.000
MAXIMUM SIMULATION TIME (YEARS)	2.000	INITIAL GROUND SURFACE TEMPERATURE (C)	10.000
TEMPERATURE GRADIENT WITHIN GROUND (K/M)	0.000	NUMBER OF LAYERS ABOVE THE AQUIFER	1.

DETAILS FOR EACH LAYER:

THERMAL CONDUCTIVITY	SPECIFIC HEAT CAPACITY	THICKNESS (M)
2.750	1499999.0	20.00

NUMBER OF LAYERS BELOW THE AQUIFER 1.

DETAILS FOR EACH LAYER:

THERMAL CONDUCTIVITY	SPECIFIC HEAT CAPACITY	THICKNESS (M)
2.750	3099999.0	40.00

FIRST DAY OF THE HEATING PERIOD : DAY 274
LAST DAY OF THE HEATING PERIOD : DAY 135

HOUSE LOAD DATA

NUMBER OF HOUSES	500	HEAT LOSS AREA PER HOUSE (SQ.M)	350.0
HEAT LOSS COEFFICIENT (W / SQ.M K)	0.490	DESIGN INDOOR TEMPERATURE (C)	18.00
DISTRIBUTION NETWORK OPTION (3 OR 4 WAY)	3		

ORETURN TEMPERATURE OPTIONS : 1. RETURN TEMPERATURE GIVEN
2. NETWORK TEMPERATURE DECREASE GIVEN

OPTION SELECTED 1

HOUSELOAD FEED TEMPERATURE IS GIVEN BY : 50.0 + 0.50 * MAX(0.0-TAMB, 0.0) WHERE TAMB = AMBIENT TEMPERATURE

RETURN TEMPERATURE OR TEMPERATURE DIFFERENCE	30.00	CASUAL GAINS (FROM PEOPLE ETC) (W/HOUSE)	400.0

TAP WATER FEED TEMPERATURE IS GIVEN BY : 50.0 + 0.50 * MAX(0.0-TAMB, 0.0) WHERE TAMB = AMBIENT TEMPERATURE

RETURN TEMPERATURE OR TEMPERATURE DIFFERENC	30.00	TAP WATER POWER REQUIREMENT (W/HOUSE)	600.
HOUSE DISTRICT HEATING NETWORK LENGTH (M)	5000.0	INSULATION THICKNESS (M)	0.057
PIPE DIAMETER (M)	0.100		
TAP WATER DISTRICT HEATING NETWORK LENGTH (M)	0.0	INSULATION THICKNESS (M)	0.057
PIPE DIAMETER (M)	0.100		

RESULTS FROM CALCULATION OF DISTRICT HEATING NETWORK LOAD AND LOSSES

TOTAL ENERGY DEMAND FROM HOUSES (MWH/YEAR)	6900.34		
TOTAL ENERGY DEMAND FOR TAP WATER (MWH/YEAR	2627.96		
TOTAL LOSS FROM SUPPLY PIPEWORK (MWH/YEAR)	350.02	TOTAL LOSS FROM RETURN PIPEWORK (MWH/YEAR)	168.54
TOTAL LOSS FROM TAP WATER SUPPLY (MWH/YEAR)	0.00	TOTAL LOSS FROM TAP WATER RETURN (MWH/YEAR)	0.00

HEAT PUMP DATA

TAP WATER HEAT PUMP DETAILS -

CARNOT EFFICIENCY FRACTION (0.25-0.65)	0.600
TEMPERATURE DIFFERENCE (EVAP. TO COND.) AT WHICH EFFICIENCY FRACTION STARTS TO FALL (K)	50.0
TEMPERATURE DIFFERENCE (EVAP. TO COND.) AT WHICH EFFICIENCY FRACTION IS ZERO (STAGNATION TEMP. DIFF.) (K)	100.0
MINIMUM EVAPORATOR OUTLET TEMPERATURE (C)	5.0
EVAPORATOR HEAT TRANSFER CAPACITY (KW/K)	30.00
MINIMUM COP FOR OPERATION OF HEAT PUMP	1.00
CONDENSER HEAT TRANSFER CAPACITY (KW/K)	40.00

HEATING SYSTEM HEAT PUMP DETAILS -

CARNOT EFFICIENCY FRACTION (0.25-0.65)	0.600
TEMPERATURE DIFFERENCE (EVAP. TO COND.) AT WHICH EFFICIENCY FRACTION STARTS TO FALL (K)	50.0
TEMPERATURE DIFFERENCE (EVAP. TO COND.) AT WHICH EFFICIENCY FRACTION IS ZERO (STAGNATION TEMP. DIFF.) (K)	100.0
MINIMUM EVAPORATOR OUTLET TEMPERATURE (C)	5.0
EVAPORATOR HEAT TRANSFER CAPACITY (KW/K)	250.00
MINIMUM COP FOR OPERATION OF HEAT PUMP	1.00
CONDENSER HEAT TRANSFER CAPACITY (KW/K)	250.00

COST DATA

COST OF COLLECTORS (/ SQ.M)	300.00 CAN$	COST OF WELLS (/ M)	1250.00 CAN$
EXPONENT FOR COST INCREASE DUE TO DEPTH	1.0000		
NUMBER OF WELLS IN SYSTEM	4	COST EXPONENT FOR NUMBER OF WELLS	1.0000
REF. FLOW FOR WELL & EQUIP. (CU.M / S)	0.0300	EXPONENT FOR WELL COST WITH FLOW	0.0000
COST OF EQUIPMENT (PUMPS ETC.)	50000.00 CAN$	EXPONENT FOR EQUIPMENT COST WITH FLOW	0.0000
GROUND SURFACE USED BY STORAGE (SQ.M)	0.	COST OF GROUND (/ SQ.M)	0.00 CAN$

HEAT PUMP COSTS

COST OF CONDENSER HEAT EXCHANGER (K/W)	0.20 CAN$	COST OF EVAPORATOR HEAT EXCHANGER (K/W)	0.20 CAN$
COST OF MOTOR (/ W INSTALLED)	0.20 CAN$	REFERENCE POWER (MW)	0.600
HEAT PUMP SCALE FACTOR FOR COSTS	-0.3000		

COST OF PIPING BETWEEN COLLECTORS AND STORAGE

DIAMETER DEPENDENT (/M(LENGTH)/M(DIAM))	1750.00 CAN$	FIXED COST (/ M)	50.00 CAN$
COST OF INSULATION OF PIPEWORK (/ CU.M)	0.00 CAN$		

AUXILIARY HEATER COSTS

INSTALLATION COST OF HEATER (/ W)	0.10 CAN$	FUEL COST (/ KWH)	0.02 CAN$
TAP WATER HEATER INSTALLATION COST (/ W)	0.00 CAN$	TAP WATER HEATER FUEL COST (/ KWH)	0.02 CAN$
COST OF FUEL FOR HEAT PUMP (/ KWH)	0.04 CAN$		

OTHER ECONOMIC PARAMETERS

DEPRECIATION TIME (YEARS)	20.	REAL INTEREST RATE (PERCENT)	5.00
FUEL INFLATION RATE ABOVE NORMAL INFLATION	2.00		

START OF CALCULATION

CHECKED THERMAL RADIUS AFTER DAY 365 OF 365 IN SIMULATION
MESH RADIUS = 200.00 M, CALCULATED RADIUS = 115.76 M
MESH RADIUS RESET TO CALCULATED RADIUS AND SIMULATION RESTARTED

CHECKED THERMAL RADIUS AFTER DAY 365 OF 365 IN SIMULATION
MESH RADIUS = 115.76 M, CALCULATED RADIUS = 115.70 M
WITHIN ACCEPTABLE LIMITS

CAPACITY REQUIREMENTS

MAXIMUM AUXILIARY HEATER POWER (HOUSE) (MW)	3.000
MAXIMUM AUXILIARY HEATER POWER (TAP WATER) (MW)	0.300
MAXIMUM CONDENSER POWER (HOUSE HEATING) (MW)	2.812
MAXIMUM CONDENSER POWER (TAP WATER) (MW)	0.300

COST FUNCTION FACTORS

TOTAL CAPITAL COST OF HEATING SYSTEM	7.201E 06 CAN$
CAPITAL COST ANNUALISATION FACTOR	7.642E-02
FIRST YEAR OPERATING COSTS FOR SYSTEM	1.106E 05 CAN$
OPERATING COST ANNUALISATION FACTOR	1.18
AVERAGE YEARLY COSTS (CAPITAL + OPERATION)	6.804E 05 CAN$

CAPITAL COST SUMMARY

ALL COSTS IN THOUSANDS OF CAN$

COST OF SOLAR COLLECTORS	3750.0
COST OF STORE EXCAVATIONS	250.0
COST OF CONCRETE	0.0
COST OF STORE INSULATION	0.0
COST OF HOUSE HEATING HEAT PUMP CONDENSER	31.5
COST OF TAP WATER HEAT PUMP CONDENSER	0.0
COST OF HOUSE HEATING HEAT PUMP EVAPORATOR	31.5
COST OF TAP WATER HEAT PUMP EVAPORATOR	0.0
COST OF HOUSE HEATING HEAT PUMP MOTOR	113.9
COST OF TAP WATER HEAT PUMP MOTOR	0.0
COST OF GROUND FOR STORE	0.0
INSTALLED COST FOR AUXILIARY HEATER (HOUSE)	300.0
INSTALLED COST OF AUXILIARY HEATER (TAP WATER)	0.0
COST OF COLLECTOR ARRAY PIPEWORK (CENTRAL)	474.0
COST OF COLLECTOR ARRAY PIPEWORK (HOUSE MOUNTED)	0.0
COST OF HOUSE HEATING DISTRIBUTION NETWORK	2250.0
COST OF TAP WATER DISTRIBUTION NETWORK	0.0

HEAT FLOW SUMMARY

COLLECTOR SUB-SYSTEM		
COLLECTOR OUTPUT	8345.77 MWH	
CENTRAL COLLECTORS		
PIPE LOSS FORWARD	-2.11 MWH	
PIPE LOSS RETURN	5.28 MWH	
COLLECTOR SUPPLY		8342.59 MWH
STORAGE SUB-SYSTEM		
STORAGE LOSSES	2080.37 MWH	
COLLECTOR SUPPLY MINUS STORAGE LOSSES		6262.22 MWH
STORED HEAT YEAR END		
MINUS YEAR BEGINNING	0.00 MWH	
COLLECTOR AND STORAGE SUPPLY		6262.22 MWH
AUXILIARY		
HEAT PUMP ELECTRIC ENERGY		
HOUSE HEAT	1600.09 MWH	
TAP WATER	477.64 MWH	
AUXILIARY HEATER		
HOUSE HEAT	999.57 MWH	
TAP WATER	707.39 MWH	
TOTAL SUPPLY		10046.91 MWH
LOAD		
DISTRIBUTION LOSS FORWARD		
HOUSE HEAT	350.02 MWH	
TAP WATER	0.00 MWH	
DISTRIBUTION LOSS RETURN		
HOUSE HEAT	168.54 MWH	
TAP WATER	0.00 MWH	
HOUSE LOAD	9528.36 MWH	
TOTAL LOAD		10046.91 MWH

ABOVE AUXILIARY FIGURES INCLUDE THE FOLLOWING AMOUNTS TO RAISE STORAGE WATER TO DUMPED TEMP.

HOUSE HEAT	0.00 MWH
TAPWATER	0.00 MWH

RATIOS

COLLECTOR SUPPLY/TOTAL LOAD	83.04 PERCENT
COLLECTOR SUPPLY MINUS STORAGE LOSSES/TOTAL LOAD	62.33 PERCENT
COLLECTOR AND STORAGE SUPPLY/TOTAL LOAD	62.33 PERCENT

TEMPERATURES OF STORAGE

START	8.0	8.0
END	11.5	8.0

CHANGE OF AVERAGE TEMPERATURE 1.741 C
MIN. TEMPERATURE 8.0 C MAX.TEMPERATURE 15.0 C
MIN CHANGE OF STORAGE 0.00 MWH MAX 0.00 MWH
DIAMETER OF CENTRAL COLLECTOR ARRAY PIPES 0.400 M
INSULATION THICKNESS ROUND PIPES 0.060 M

HEAT PUMP PERFORMANCE

	EL-MOTOR	COND POWER	C.O.P.
TAP WATER	477.64	1929.57	4.04
HOUSE HEAT	1600.09	6426.79	4.02

SPECIFIC COSTS

	INVESTMENT (CAN$/MWH/Y)	CAPITAL (CAN$/MWH)	OPERATION (CAN$/MWH)	TOTAL (CAN$/MWH)
SOLAR COLLECTORS	449.64	34.36	0.00	34.36
COLL. PIPEWORK	56.83	4.34	0.00	4.34
STORAGE	29.98	2.29	0.00	2.29
HEAT PUMP	21.20	1.62	10.76	12.38
TOTAL SOLAR SYSTEM	557.66	42.62	10.76	53.38
AUXILIARY	175.75	13.43	23.65	37.08
TOTAL SYSTEM	492.77	37.66	12.95	50.61

TOTAL SOLAR COST (/MWH DELIVERED FROM SOLAR SYSTEM) 56.76

AQUIFER PERFORMANCE

MAXIMUM RADIUS OF STORAGE (M)	115.70
MAXIMUM VOLUME OF STORAGE (000 M**3)	841.07
FINAL RADIUS OF STORAGE (M)	10.74
NET VOLUME OF WATER INJECTED INTO STORAGE (000 M**3)	7.24
AVERAGE TEMPERATURE OF INJECTED WATER (C)	15.00
TOTAL INJECTED VOLUME (000 M**3)	1035.22
AVERAGE EVAPORATOR FEED TEMPERATURE - HOUSE (C)	12.70
AVERAGE EVAPORATOR DUMP TEMPERATURE - HOUSE (C)	8.68
AVERAGE TEMPERATURE DROP ACROSS EVAPORATOR (C)	4.02
VOLUME DUMPED FROM EVAPORATOR (000 M**3)	1033.49
AVERAGE DISTRIBUTION FEED TEMPERATURE - HOUSE (C)	0.00
AVERAGE DISTRIBUTION DUMP TEMPERATURE - HOUSE (C)	0.00
AVERAGE TEMP DROP ACROSS DISTRIBUTION SYSTEM (C)	0.00
VOLUME DUMPED FROM DISTRIBUTION SYSTEM (000 M**3)	0.00
AVERAGE EVAPORATOR FEED TEMPERATURE - TAPWATER (C)	14.54
AVERAGE EVAPORATOR DUMP TEMPERATURE - TAPWATER (C)	7.01
AVERAGE TEMPERATURE DROP ACROSS EVAPORATOR (C)	7.52
VOLUME DUMPED FROM EVAPORATOR (000 M**3)	166.18
AVERAGE DISTN FEED TEMPERATURE - TAPWATER (C)	0.00
AVERAGE DISTN DUMP TEMPERATURE - TAPWATER (C)	0.00
AVERAGE TEMP DROP ACROSS DISTRIBUTION SYSTEM (C)	0.00
VOLUME DUMPED FROM DISTRIBUTION SYSTEM (000 M**3)	0.00

```
 IEA DATA PROGRAM VERSION 1
  MONTH END DAYS  31  28  31  30  31  30  31  31  30  31  30  31
  COLLECTOR SWITCHES 1=ON,0=OFF

   FLAT PLATE=1 SALT POND=0 EVAC TUBE=0
   CENTRAL RECV=0 PARB TROUGH=0 SHAL POND=0
  BOES MODEL=1
     ALPHA         UL1          UL2          BO          TILT          DIR          RHO
 0.7530E 00   0.5250E 01       0.0000   0.1000E 00   0.4590E 02       0.0000   0.2000E 00
 0.3370E 00   0.2900E 00       0.0000   0.5000E-01       0.0000       0.0000       0.0000
 0.5100E 00   0.1310E 01       0.0000   0.1700E 00   0.4590E 02       0.0000   0.2000E 00
 0.9800E 00       0.0000       0.0000       0.0000       0.0000       0.0000       0.0000
 0.8070E 00   0.8900E-01   0.8690E 00       0.0000       0.0000       0.0000   0.2000E 00
 0.6400E 00   0.4400E 01       0.0000       0.0000       0.0000       0.0000       0.0000
LAT=45.90 LONG= 0.00 TEMPS=  5. 15. 25. 35. 45.
TAMB=10.  TROOM=18.


                * IEA * UNSORT OUTPUT SUMMARY *

                    FOR COLLECTOR NUMBER  :  1
                    FOR LOCATION          :FRED

 - TEMPERATURES       IN     DEGREES CELCIUS
 - ALL ENERGIES       IN     MEGAJOULES/MONTH OR YEAR
```

MONTH	J	F	M	A	M	J	J	A	S	O	N	D	YEAR
AMB. TEMPERATURE	-11.9	-8.0	-2.4	4.9	11.4	17.4	19.4	18.6	13.6	6.9	0.2	-5.4	5.4
TEMP. FOR LOAD MOD	-11.9	-8.0	-2.2	5.3	13.1	17.2	17.7	17.6	15.7	8.3	0.4	-5.4	5.7
DIRECT NORMAL RAD.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
TOTAL HORIZONTAL	178.	231.	374.	452.	539.	606.	618.	509.	373.	268.	142.	129.	4419.
TOTAL INCIDENT	348.	390.	479.	475.	493.	529.	562.	503.	440.	387.	240.	272.	5117.
COLLECTED AT 5.	183.	227.	307.	352.	412.	482.	520.	470.	383.	302.	158.	156.	3951.
COLLECTED AT 15.	149.	188.	253.	290.	335.	402.	442.	396.	320.	248.	124.	125.	3272.
COLLECTED AT 25.	122.	157.	210.	241.	272.	331.	369.	326.	265.	203.	99.	99.	2694.
COLLECTED AT 35.	97.	129.	173.	201.	224.	275.	311.	267.	223.	168.	78.	76.	2224.
COLLECTED AT 45.	75.	105.	143.	167.	184.	229.	259.	218.	190.	138.	59.	56.	1823.
OP. HOURS AT 5.	199.	228.	304.	359.	426.	428.	419.	395.	343.	308.	210.	190.	3809.
OP. HOURS AT 15.	160.	179.	257.	285.	381.	408.	403.	390.	327.	263.	151.	144.	3348.
OP. HOURS AT 25.	134.	156.	206.	229.	286.	336.	349.	338.	250.	206.	120.	130.	2740.
OP. HOURS AT 35.	128.	137.	176.	198.	232.	257.	282.	282.	195.	173.	104.	114.	2278.
OP. HOURS AT 45.	108.	121.	149.	167.	198.	227.	256.	247.	165.	142.	95.	104.	1979.

IEA SOLAR HEATING PROGRAMME TASK VII : INTERSEASONAL STORAGE OF SOLAR ENERGY. OUTPUT FROM MINSUN (VERSION 4 DATE 83-11-29)

RUN TITLE : CANADIAN NATIONAL EVALUATION WITH AQUIFER STORAGE

S U M M A R Y O F I N P U T D A T A .

STORAGE OPTION SELECTED :

AQUIFER STORAGE MODEL (LUND)

W E A T H E R D A T A D E T A I L S

IEA MODEL - DATA PRE-PROCESSED BY PROGRAM UMSORT

TITLE CARD (CITY AND COLLECTOR TYPE) : FRED BOES FLAT PLAT

WEATHER DATA FILE HAS BEEN READ.

LAST DATE READ WAS	135		
HEATING IF AMBIENT TEMP. LESS THAN (C)	10.0	INDOOR TEMPERATURE (C)	18.0

RUN OPTIONS SELECTED FOR THIS RUN :

SINGULAR POINT CALCULATION
SEPARATE TAP WATER SYSTEM

I N S U L A T I O N D A T A

COLLECTOR PIPE INSULATION CONDUCTIVITY (W/MK)	0.040	EARTH TEMPERATURE (C)	10.00
DIAMETER DEPENDENT INSULATION THICKNESS (M/M)	0.100	FIXED INSULATION THICKNESS (M)	0.020

C O L L E C T O R D A T A (CENTRAL MOUNTED)

OPTION (MUST BE 3.)	3.		
MAX. (COLL. OUTLET - TOP STORAGE TEMP.) (C)	0.0	COLLECTOR AREA (SQ.M)	15000.0
MAXIMUM COLLECTOR OUTLET TEMPERATURE (C)	15.0	OUTLET TEMP. AT WHICH FLOW IS INCREASED (C)	15.0
NORMAL FLOW RATE (KG / S SQ.M)	0.0001	MAXIMUM FLOW RATE (KG / S SQ.M)	0.0200
COLLECTOR PIPING NETWORK LENGTH (M)	316.0	INSULATION THICKNESS (M)	0.000
PIPE DIAMETER (M)	0.400		

STORAGE DATA (AQUIFER STORAGE MODEL)

HEIGHT OF AQUIFER (M)	20.0	THERMAL RADIUS (M)	200.00
HORIZONTAL THERMAL CONDUCTIVITY (W/MK)	2.000	VERTICAL THERMAL CONDUCTIVITY (W/MK)	2.750
HEAT CAPACITY IN AQUIFER (J/M3K)	2499999.0	AQUIFER SUPPLY TEMPERATURE (C)	8.000
MAXIMUM SIMULATION TIME (YEARS)	2.000	INITIAL GROUND SURFACE TEMPERATURE (C)	10.000
TEMPERATURE GRADIENT WITHIN GROUND (K/M)	0.000	NUMBER OF LAYERS ABOVE THE AQUIFER	1.

DETAILS FOR EACH LAYER:	THERMAL CONDUCTIVITY	SPECIFIC HEAT CAPACITY	THICKNESS (M)
	2.750	1499999.0	20.00

NUMBER OF LAYERS BELOW THE AQUIFER 1.

DETAILS FOR EACH LAYER:	THERMAL CONDUCTIVITY	SPECIFIC HEAT CAPACITY	THICKNESS (M)
	2.750	3099999.0	40.00

FIRST DAY OF THE HEATING PERIOD : DAY 274
LAST DAY OF THE HEATING PERIOD : DAY 135

HOUSE LOAD DATA

NUMBER OF HOUSES	500	HEAT LOSS AREA PER HOUSE (SQ.M)	350.0
HEAT LOSS COEFFICIENT (W / SQ.M K)	0.490	DESIGN INDOOR TEMPERATURE (C)	18.00
DISTRIBUTION NETWORK OPTION (3 OR 4 WAY)	3		

RETURN TEMPERATURE OPTIONS : 1. RETURN TEMPERATURE GIVEN
2. NETWORK TEMPERATURE DECREASE GIVEN

OPTION SELECTED 1

HOUSELOAD FEED TEMPERATURE IS GIVEN BY : 50.0 + 0.50 * MAX(0.0-TAMB, 0.0) WHERE TAMB = AMBIENT TEMPERATURE

RETURN TEMPERATURE OR TEMPERATURE DIFFERENCE	30.00	CASUAL GAINS (FROM PEOPLE ETC) (W/HOUSE)	400.0
TAP WATER FEED TEMPERATURE IS GIVEN BY :	50.0 + 0.50 * MAX(	0.0-TAMB, 0.0) WHERE TAMB = AMBIENT TEMPERATURE	
RETURN TEMPERATURE OR TEMPERATURE DIFFERENC	30.00	TAP WATER POWER REQUIREMENT (W/HOUSE)	600.
HOUSE DISTRICT HEATING NETWORK LENGTH (M)	5000.0	INSULATION THICKNESS (M)	0.057
PIPE DIAMETER (M)	0.100		
TAP WATER DISTRICT HEATING NETWORK LENGTH (M)	0.0	INSULATION THICKNESS (M)	0.057
PIPE DIAMETER (M)	0.100		

RESULTS FROM CALCULATION OF DISTRICT HEATING NETWORK LOAD AND LOSSES

TOTAL ENERGY DEMAND FROM HOUSES (MWH/YEAR)	7786.84		
TOTAL ENERGY DEMAND FOR TAP WATER (MWH/YEAR	2627.96		
TOTAL LOSS FROM SUPPLY PIPEWORK (MWH/YEAR)	361.35	TOTAL LOSS FROM RETURN PIPEWORK (MWH/YEAR)	171.30
TOTAL LOSS FROM TAP WATER SUPPLY (MWH/YEAR)	0.00	TOTAL LOSS FROM TAP WATER RETURN (MWH/YEAR)	0.00

HEAT PUMP DATA

TAP WATER HEAT PUMP DETAILS -

CARNOT EFFICIENCY FRACTION (0.25-0.65)	0.600		
TEMPERATURE DIFFERENCE (EVAP. TO COND.) AT WHICH EFFICIENCY FRACTION STARTS TO FALL (K)			50.0
TEMPERATURE DIFFERENCE (EVAP. TO COND.) AT WHICH EFFICIENCY FRACTION IS ZERO (STAGNATION TEMP. DIFF.) (K)			100.0
MINIMUM EVAPORATOR OUTLET TEMPERATURE (C)	5.0	MINIMUM COP FOR OPERATION OF HEAT PUMP	1.00
EVAPORATOR HEAT TRANSFER CAPACITY (KW/K)	30.00	CONDENSER HEAT TRANSFER CAPACITY (KW/K)	40.00

HEATING SYSTEM HEAT PUMP DETAILS -

CARNOT EFFICIENCY FRACTION (0.25-0.65)	0.600		
TEMPERATURE DIFFERENCE (EVAP. TO COND.) AT WHICH EFFICIENCY FRACTION STARTS TO FALL (K)			50.0
TEMPERATURE DIFFERENCE (EVAP. TO COND.) AT WHICH EFFICIENCY FRACTION IS ZERO (STAGNATION TEMP. DIFF.) (K)			100.0
MINIMUM EVAPORATOR OUTLET TEMPERATURE (C)	5.0	MINIMUM COP FOR OPERATION OF HEAT PUMP	1.00
EVAPORATOR HEAT TRANSFER CAPACITY (KW/K)	225.00	CONDENSER HEAT TRANSFER CAPACITY (KW/K)	225.00

COST DATA

COST OF COLLECTORS (/ SQ.M)	300.00 CAN$	COST OF WELLS (/ M)	1250.00 CAN$
EXPONENT FOR COST INCREASE DUE TO DEPTH	1.0000		
NUMBER OF WELLS IN SYSTEM	4	COST EXPONENT FOR NUMBER OF WELLS	1.0000
REF. FLOW FOR WELL & EQUIP. (CU.M / S)	0.0300	EXPONENT FOR WELL COST WITH FLOW	0.0000
COST OF EQUIPMENT (PUMPS ETC.)	50000.00 CAN$	EXPONENT FOR EQUIPMENT COST WITH FLOW	0.0000
GROUND SURFACE USED BY STORAGE (SQ.M)	0.	COST OF GROUND (/ SQ.M)	0.00 CAN$

HEAT PUMP COSTS

COST OF CONDENSER HEAT EXCHANGER (K/W)	0.20 CAN$	COST OF EVAPORATOR HEAT EXCHANGER (K/W)	0.20 CAN$
COST OF MOTOR (/ W INSTALLED)	0.20 CAN$	REFERENCE POWER (MW)	0.600
HEAT PUMP SCALE FACTOR FOR COSTS	-0.3000		

COST OF PIPING BETWEEN COLLECTORS AND STORAGE

DIAMETER DEPENDENT (/M(LENGTH)/M(DIAM))	1750.00 CAN$	FIXED COST (/ M)	50.00 CAN$
COST OF INSULATION OF PIPEWORK (/ CU.M)	0.00 CAN$		

AUXILIARY HEATER COSTS

INSTALLATION COST OF HEATER (/ W)	0.10 CAN$	FUEL COST (/ KWH)	0.02 CAN$
TAP WATER HEATER INSTALLATION COST (/ W)	0.00 CAN$	TAP WATER HEATER FUEL COST (/ KWH)	0.02 CAN$
COST OF FUEL FOR HEAT PUMP (/ KWH)	0.04 CAN$		

OTHER ECONOMIC PARAMETERS

DEPRECIATION TIME (YEARS)	20.	REAL INTEREST RATE (PERCENT)	5.00
FUEL INFLATION RATE ABOVE NORMAL INFLATION	2.00		

START OF CALCULATION

CHECKED THERMAL RADIUS AFTER DAY 365 OF 365 IN SIMULATION
MESH RADIUS = 200.00 M, CALCULATED RADIUS = 120.49 M
WITHIN ACCEPTABLE LIMITS

CAPACITY REQUIREMENTS

MAXIMUM AUXILIARY HEATER POWER (HOUSE) (MW)	3.639
MAXIMUM AUXILIARY HEATER POWER (TAP WATER) (MW)	0.300
MAXIMUM CONDENSER POWER (HOUSE HEATING) (MW)	3.429
MAXIMUM CONDENSER POWER (TAP WATER) (MW)	0.300

COST FUNCTION FACTORS

TOTAL CAPITAL COST OF HEATING SYSTEM	8.055E 06 CAN$
CAPITAL COST ANNUALISATION FACTOR	7.642E-02
FIRST YEAR OPERATING COSTS FOR SYSTEM	1.316E 05 CAN$
OPERATING COST ANNUALISATION FACTOR	1.18
AVERAGE YEARLY COSTS (CAPITAL + OPERATION)	7.704E 05 CAN$

CAPITAL COST SUMMARY

ALL COSTS IN THOUSANDS OF CAN$

COST OF SOLAR COLLECTORS	4500.0
COST OF STORE EXCAVATIONS	250.0
COST OF CONCRETE	0.0
COST OF STORE INSULATION	0.0
COST OF HOUSE HEATING HEAT PUMP CONDENSER	26.7
COST OF TAP WATER HEAT PUMP CONDENSER	0.0
COST OF HOUSE HEATING HEAT PUMP EVAPORATOR	26.7
COST OF TAP WATER HEAT PUMP EVAPORATOR	0.0
COST OF HOUSE HEATING HEAT PUMP MOTOR	163.7
COST OF TAP WATER HEAT PUMP MOTOR	0.0
COST OF GROUND FOR STORE	0.0
INSTALLED COST FOR AUXILIARY HEATER (HOUSE)	363.9
INSTALLED COST OF AUXILIARY HEATER (TAP WATER)	0.0
COST OF COLLECTOR ARRAY PIPEWORK (CENTRAL)	474.0
COST OF COLLECTOR ARRAY PIPEWORK (HOUSE MOUNTED)	0.0
COST OF HOUSE HEATING DISTRIBUTION NETWORK	2250.0
COST OF TAP WATER DISTRIBUTION NETWORK	0.0

HEAT FLOW SUMMARY

COLLECTOR SUB-SYSTEM		
COLLECTOR OUTPUT	9621.69 MWH	
CENTRAL COLLECTORS		
PIPE LOSS FORWARD	-2.12 MWH	
PIPE LOSS RETURN	5.31 MWH	
COLLECTOR SUPPLY		9618.50 MWH
STORAGE SUB-SYSTEM		
STORAGE LOSSES	2092.98 MWH	
COLLECTOR SUPPLY MINUS STORAGE LOSSES		7525.52 MWH
STORED HEAT YEAR END		
MINUS YEAR BEGINNING	0.00 MWH	
COLLECTOR AND STORAGE SUPPLY		7525.52 MWH
AUXILIARY		
HEAT PUMP ELECTRIC ENERGY		
HOUSE HEAT	2150.20 MWH	
TAP WATER	560.86 MWH	
AUXILIARY HEATER		
HOUSE HEAT	307.23 MWH	
TAP WATER	403.68 MWH	
TOTAL SUPPLY		10947.49 MWH
LOAD		
DISTRIBUTION LOSS FORWARD		
HOUSE HEAT	361.35 MWH	
TAP WATER	0.00 MWH	
DISTRIBUTION LOSS RETURN		
HOUSE HEAT	171.30 MWH	
TAP WATER	0.00 MWH	
HOUSE LOAD	10414.84 MWH	
TOTAL LOAD		10947.49 MWH

ABOVE AUXILIARY FIGURES INCLUDE THE FOLLOWING AMOUNTS TO RAISE STORAGE WATER TO DUMPED TEMP.

HOUSE HEAT	0.00 MWH
TAPWATER	0.00 MWH

RATIOS

COLLECTOR SUPPLY/TOTAL LOAD	87.86 PERCENT
COLLECTOR SUPPLY MINUS STORAGE LOSSES/TOTAL LOAD	68.74 PERCENT
COLLECTOR AND STORAGE SUPPLY/TOTAL LOAD	68.74 PERCENT

TEMPERATURES OF STORAGE

START	8.0	8.0
END	10.9	8.0

CHANGE OF AVERAGE TEMPERATURE 1.473 C
MIN. TEMPERATURE 8.0 C MAX.TEMPERATURE 14.9 C
MIN CHANGE OF STORAGE 0.00 MWH MAX 0.00 MWH
DIAMETER OF CENTRAL COLLECTOR ARRAY PIPES 0.400 M
INSULATION THICKNESS ROUND PIPES 0.060 M

HEAT PUMP PERFORMANCE

	EL-MOTOR	COND POWER	C.O.P.
TAP WATER	560.86	2231.97	3.98
HOUSE HEAT	2150.20	8019.26	3.73

SPECIFIC COSTS

	INVESTMENT (CAN$/MWH/Y)	CAPITAL (CAN$/MWH)	OPERATION (CAN$/MWH)	TOTAL (CAN$/MWH)
SOLAR COLLECTORS	439.60	33.60	0.00	33.60
COLL. PIPEWORK	46.30	3.54	0.00	3.54
STORAGE	24.42	1.87	0.00	1.87
HEAT PUMP	21.20	1.62	13.12	14.74
TOTAL SOLAR SYSTEM	531.53	40.62	13.12	53.74
AUXILIARY	511.87	39.12	28.83	67.95
TOTAL SYSTEM	530.25	40.52	14.14	54.66

TOTAL SOLAR COST (/MWH DELIVERED FROM SOLAR SYSTEM) 55.25

AQUIFER PERFORMANCE

MAXIMUM RADIUS OF STORAGE (M)	120.49
MAXIMUM VOLUME OF STORAGE (000 M**3)	912.21
FINAL RADIUS OF STORAGE (M)	14.65
NET VOLUME OF WATER INJECTED INTO STORAGE (000 M**3)	13.48
AVERAGE TEMPERATURE OF INJECTED WATER (C)	15.00
TOTAL INJECTED VOLUME (000 M**3)	1187.69
AVERAGE EVAPORATOR FEED TEMPERATURE - HOUSE (C)	13.44
AVERAGE EVAPORATOR DUMP TEMPERATURE - HOUSE (C)	8.43
AVERAGE TEMPERATURE DROP ACROSS EVAPORATOR (C)	5.01
VOLUME DUMPED FROM EVAPORATOR (000 M**3)	1009.20
AVERAGE DISTRIBUTION FEED TEMPERATURE - HOUSE (C)	0.00
AVERAGE DISTRIBUTION DUMP TEMPERATURE - HOUSE (C)	0.00
AVERAGE TEMP DROP ACROSS DISTRIBUTION SYSTEM (C)	0.00
VOLUME DUMPED FROM DISTRIBUTION SYSTEM (000 M**3)	0.00
AVERAGE EVAPORATOR FEED TEMPERATURE - TAPWATER (C)	14.50
AVERAGE EVAPORATOR DUMP TEMPERATURE - TAPWATER (C)	7.01
AVERAGE TEMPERATURE DROP ACROSS EVAPORATOR (C)	7.49
VOLUME DUMPED FROM EVAPORATOR (000 M**3)	192.22
AVERAGE DISTN FEED TEMPERATURE - TAPWATER (C)	0.00
AVERAGE DISTN DUMP TEMPERATURE - TAPWATER (C)	0.00
AVERAGE TEMP DROP ACROSS DISTRIBUTION SYSTEM (C)	0.00
VOLUME DUMPED FROM DISTRIBUTION SYSTEM (000 M**3)	0.00

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 IEA DATA PROGRAM VERSION 1
  MONTH END DAYS  31  28  31  30  31  30  31  31  30  31  30  31
  COLLECTOR SWITCHES 1=ON,0=OFF

   FLAT PLATE=1 SALT POND=0 EVAC TUBE=0
   CENTRAL RECV=0 PARB TROUGH=0 SHAL POND=0
  BOES MODEL=1
     ALPHA         UL1          UL2       BO          TILT          DIR          RHO
 0.7530E 00   0.5250E 01       0.0000   0.1000E 00  0.4990E 02       0.0000   0.2000E 00
 0.3370E 00   0.2900E 00       0.0000   0.5000E-01      0.0000       0.0000       0.0000
 0.5100E 00   0.1310E 01       0.0000   0.1700E 00  0.4990E 02       0.0000   0.2000E 00
 0.9800E 00        0.0000      0.0000        0.0000      0.0000       0.0000       0.0000
 0.8070E 00   0.8900E-01   0.8690E 00        0.0000      0.0000       0.0000   0.2000E 00
 0.6400E 00   0.4400E 01       0.0000        0.0000      0.0000       0.0000       0.0000
LAT=49.90 LONG= 0.00 TEMPS=  5. 15. 25. 35. 45.
TAMB=10.  TROOM=18.


                  * IEA * UNSORT OUTPUT SUMMARY *

                       FOR COLLECTOR NUMBER  :  1
                       FOR LOCATION          :WINN

 - TEMPERATURES       IN     DEGREES CELCIUS
 - ALL ENERGIES       IN     MEGAJOULES/MONTH OR YEAR
```

MONTH	J	F	M	A	M	J	J	A	S	O	N	D	YEAR
AMB. TEMPERATURE	-17.9	-17.3	-10.3	3.3	10.5	16.4	19.0	18.6	12.1	5.6	-3.8	-15.4	1.7
TEMP. FOR LOAD MOD	-17.9	-17.3	-10.3	3.9	11.9	16.8	17.5	17.3	13.5	6.5	-3.8	-15.4	1.9
DIRECT NORMAL RAD.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
TOTAL HORIZONTAL	164.	242.	443.	519.	649.	665.	714.	599.	413.	235.	130.	125.	4897.
TOTAL INCIDENT	419.	472.	633.	570.	608.	584.	645.	618.	519.	361.	254.	301.	5983.
COLLECTED AT 5.	214.	241.	371.	409.	485.	514.	577.	552.	432.	273.	151.	147.	4367.
COLLECTED AT 15.	180.	201.	318.	345.	408.	431.	493.	477.	367.	222.	117.	117.	3677.
COLLECTED AT 25.	148.	165.	271.	292.	343.	358.	418.	408.	311.	179.	92.	91.	3076.
COLLECTED AT 35.	119.	134.	229.	246.	288.	301.	356.	350.	263.	146.	71.	69.	2572.
COLLECTED AT 45.	93.	106.	192.	206.	240.	251.	301.	299.	220.	118.	53.	51.	2130.
OP. HOURS AT 5.	194.	225.	299.	364.	433.	451.	453.	399.	357.	296.	208.	164.	3843.
OP. HOURS AT 15.	174.	203.	266.	310.	378.	414.	426.	388.	325.	252.	148.	145.	3429.
OP. HOURS AT 25.	160.	180.	237.	257.	309.	339.	359.	336.	270.	200.	121.	133.	2901.
OP. HOURS AT 35.	149.	154.	207.	224.	270.	275.	302.	288.	238.	155.	103.	106.	2471.
OP. HOURS AT 45.	131.	142.	194.	201.	238.	248.	280.	263.	206.	143.	92.	84.	2222.

IEA SOLAR HEATING PROGRAMME TASK VII : INTERSEASONAL STORAGE OF SOLAR ENERGY. OUTPUT FROM MINSUN (VERSION 4 DATE 83-11-29)

RUN TITLE : CANADIAN NATIONAL EVALUATION WITH AQUIFER STORAGE

S U M M A R Y O F I N P U T D A T A .

STORAGE OPTION SELECTED :

AQUIFER STORAGE MODEL (LUND)

W E A T H E R D A T A D E T A I L S

IEA MODEL - DATA PRE-PROCESSED BY PROGRAM UMSORT

TITLE CARD (CITY AND COLLECTOR TYPE) : WINN BOES FLAT PLAT

WEATHER DATA FILE HAS BEEN READ.

LAST DATE READ WAS	135	INDOOR TEMPERATURE (C)	18.0
HEATING IF AMBIENT TEMP. LESS THAN (C)	10.0		

RUN OPTIONS SELECTED FOR THIS RUN :

SINGULAR POINT CALCULATION
SEPARATE TAP WATER SYSTEM

I N S U L A T I O N D A T A

COLLECTOR PIPE INSULATION CONDUCTIVITY (W/MK)	0.040	EARTH TEMPERATURE (C)	10.00
DIAMETER DEPENDENT INSULATION THICKNESS (M/M)	0.100	FIXED INSULATION THICKNESS (M)	0.020

C O L L E C T O R D A T A (CENTRAL MOUNTED)

OPTION (MUST BE 3.)	3.	COLLECTOR AREA (SQ.M)	15000.0
MAX. (COLL. OUTLET - TOP STORAGE TEMP.) (C)	0.0	OUTLET TEMP. AT WHICH FLOW IS INCREASED (C)	15.0
MAXIMUM COLLECTOR OUTLET TEMPERATURE (C)	15.0		
NORMAL FLOW RATE (KG / S SQ.M)	0.0001	MAXIMUM FLOW RATE (KG / S SQ.M)	0.0200
COLLECTOR PIPING NETWORK LENGTH (M)	316.0	INSULATION THICKNESS (M)	0.000
PIPE DIAMETER (M)	0.400		

S T O R A G E D A T A (AQUIFER STORAGE MODEL)

HEIGHT OF AQUIFER (M)	20.0	THERMAL RADIUS (M)	200.00
HORIZONTAL THERMAL CONDUCTIVITY (W/MK)	2.000	VERTICAL THERMAL CONDUCTIVITY (W/MK)	2.750
HEAT CAPACITY IN AQUIFER (J/M3K)	2499999.0	AQUIFER SUPPLY TEMPERATURE (C)	8.000
MAXIMUM SIMULATION TIME (YEARS)	2.000	INITIAL GROUND SURFACE TEMPERATURE (C)	10.000
TEMPERATURE GRADIENT WITHIN GROUND (K/M)	0.000	NUMBER OF LAYERS ABOVE THE AQUIFER	1.

DETAILS FOR EACH LAYER:	THERMAL CONDUCTIVITY	SPECIFIC HEAT CAPACITY	THICKNESS (M)
	2.750	1499999.0	20.00

NUMBER OF LAYERS BELOW THE AQUIFER 1.

DETAILS FOR EACH LAYER:	THERMAL CONDUCTIVITY	SPECIFIC HEAT CAPACITY	THICKNESS (M)
	2.750	3099999.0	40.00

FIRST DAY OF THE HEATING PERIOD : DAY 274
LAST DAY OF THE HEATING PERIOD : DAY 135

H O U S E L O A D D A T A

NUMBER OF HOUSES	500	HEAT LOSS AREA PER HOUSE (SQ.M)	350.0
HEAT LOSS COEFFICIENT (W / SQ.M K)	0.490	DESIGN INDOOR TEMPERATURE (C)	18.00
DISTRIBUTION NETWORK OPTION (3 OR 4 WAY)	3		

ORETURN TEMPERATURE OPTIONS : 1. RETURN TEMPERATURE GIVEN
2. NETWORK TEMPERATURE DECREASE GIVEN

OPTION SELECTED 1

HOUSELOAD FEED TEMPERATURE IS GIVEN BY : 50.0 + 0.50 * MAX(0.0-TAMB, 0.0) WHERE TAMB = AMBIENT TEMPERATURE

RETURN TEMPERATURE OR TEMPERATURE DIFFERENCE	30.00	CASUAL GAINS (FROM PEOPLE ETC) (W/HOUSE)	400.0

TAP WATER FEED TEMPERATURE IS GIVEN BY : 50.0 + 0.50 * MAX(0.0-TAMB, 0.0) WHERE TAMB = AMBIENT TEMPERATURE

RETURN TEMPERATURE OR TEMPERATURE DIFFERENC	30.00	TAP WATER POWER REQUIREMENT (W/HOUSE)	600.
HOUSE DISTRICT HEATING NETWORK LENGTH (M)	5000.0	INSULATION THICKNESS (M)	0.057
PIPE DIAMETER (M)	0.100		
TAP WATER DISTRICT HEATING NETWORK LENGTH (M)	0.0	INSULATION THICKNESS (M)	0.057
PIPE DIAMETER (M)	0.100		

RESULTS FROM CALCULATION OF DISTRICT HEATING NETWORK LOAD AND LOSSES

TOTAL ENERGY DEMAND FROM HOUSES (MWH/YEAR)	10333.55		
TOTAL ENERGY DEMAND FOR TAP WATER (MWH/YEAR	2627.96		
TOTAL LOSS FROM SUPPLY PIPEWORK (MWH/YEAR)	388.03	TOTAL LOSS FROM RETURN PIPEWORK (MWH/YEAR)	174.26
TOTAL LOSS FROM TAP WATER SUPPLY (MWH/YEAR)	0.00	TOTAL LOSS FROM TAP WATER RETURN (MWH/YEAR)	0.00

HEAT PUMP DATA

TAP WATER HEAT PUMP DETAILS -

CARNOT EFFICIENCY FRACTION (0.25-0.65)	0.600		
TEMPERATURE DIFFERENCE (EVAP. TO COND.) AT WHICH EFFICIENCY FRACTION STARTS TO FALL (K)			50.0
TEMPERATURE DIFFERENCE (EVAP. TO COND.) AT WHICH EFFICIENCY FRACTION IS ZERO (STAGNATION TEMP. DIFF.) (K)			100.0
MINIMUM EVAPORATOR OUTLET TEMPERATURE (C)	5.0	MINIMUM COP FOR OPERATION OF HEAT PUMP	1.00
EVAPORATOR HEAT TRANSFER CAPACITY (KW/K)	30.00	CONDENSER HEAT TRANSFER CAPACITY (KW/K)	40.00

HEATING SYSTEM HEAT PUMP DETAILS -

CARNOT EFFICIENCY FRACTION (0.25-0.65)	0.600		
TEMPERATURE DIFFERENCE (EVAP. TO COND.) AT WHICH EFFICIENCY FRACTION STARTS TO FALL (K)			50.0
TEMPERATURE DIFFERENCE (EVAP. TO COND.) AT WHICH EFFICIENCY FRACTION IS ZERO (STAGNATION TEMP. DIFF.) (K)			100.0
MINIMUM EVAPORATOR OUTLET TEMPERATURE (C)	5.0	MINIMUM COP FOR OPERATION OF HEAT PUMP	1.00
EVAPORATOR HEAT TRANSFER CAPACITY (KW/K)	250.00	CONDENSER HEAT TRANSFER CAPACITY (KW/K)	250.00

COST DATA

COST OF COLLECTORS (/ SQ.M)	300.00 CAN$	COST OF WELLS (/ M)	1250.00 CAN$
EXPONENT FOR COST INCREASE DUE TO DEPTH	1.0000		
NUMBER OF WELLS IN SYSTEM	4	COST EXPONENT FOR NUMBER OF WELLS	1.0000
REF. FLOW FOR WELL & EQUIP. (CU.M / S)	0.0300	EXPONENT FOR WELL COST WITH FLOW	0.0000
COST OF EQUIPMENT (PUMPS ETC.)	50000.00 CAN$	EXPONENT FOR EQUIPMENT COST WITH FLOW	0.0000
GROUND SURFACE USED BY STORAGE (SQ.M)	0.	COST OF GROUND (/ SQ.M)	0.00 CAN$

HEAT PUMP COSTS

COST OF CONDENSER HEAT EXCHANGER (K/W)	0.20 CAN$	COST OF EVAPORATOR HEAT EXCHANGER (K/W)	0.20 CAN$
COST OF MOTOR (/ W INSTALLED)	0.20 CAN$	REFERENCE POWER (MW)	0.600
HEAT PUMP SCALE FACTOR FOR COSTS	-0.3000		

COST OF PIPING BETWEEN COLLECTORS AND STORAGE

DIAMETER DEPENDENT (/M(LENGTH)/M(DIAM))	1750.00 CAN$	FIXED COST (/ M)	50.00 CAN$
COST OF INSULATION OF PIPEWORK (/ CU.M)	0.00 CAN$		

AUXILIARY HEATER COSTS

INSTALLATION COST OF HEATER (/ W)	0.10 CAN$	FUEL COST (/ KWH)	0.02 CAN$
TAP WATER HEATER INSTALLATION COST (/ W)	0.00 CAN$	TAP WATER HEATER FUEL COST (/ KWH)	0.02 CAN$
COST OF FUEL FOR HEAT PUMP (/ KWH)	0.02 CAN$		

OTHER ECONOMIC PARAMETERS

DEPRECIATION TIME (YEARS)	20.	REAL INTEREST RATE (PERCENT)	5.00
FUEL INFLATION RATE ABOVE NORMAL INFLATION	2.00		

START OF CALCULATION

CHECKED THERMAL RADIUS AFTER DAY 365 OF 365 IN SIMULATION
MESH RADIUS = 200.00 M, CALCULATED RADIUS = 129.72 M
WITHIN ACCEPTABLE LIMITS

CAPACITY REQUIREMENTS

MAXIMUM AUXILIARY HEATER POWER (HOUSE) (MW)	3.206
MAXIMUM AUXILIARY HEATER POWER (TAP WATER) (MW)	0.300
MAXIMUM CONDENSER POWER (HOUSE HEATING) (MW)	4.497
MAXIMUM CONDENSER POWER (TAP WATER) (MW)	0.300

COST FUNCTION FACTORS

TOTAL CAPITAL COST OF HEATING SYSTEM	8.099E 06 CAN$
CAPITAL COST ANNUALISATION FACTOR	7.642E-02
FIRST YEAR OPERATING COSTS FOR SYSTEM	8.569E 04 CAN$
OPERATING COST ANNUALISATION FACTOR	1.18
AVERAGE YEARLY COSTS (CAPITAL + OPERATION)	7.198E 05 CAN$

CAPITAL COST SUMMARY

ALL COSTS IN THOUSANDS OF CAN$

COST OF SOLAR COLLECTORS	4500.0
COST OF STORE EXCAVATIONS	250.0
COST OF CONCRETE	0.0
COST OF STORE INSULATION	0.0
COST OF HOUSE HEATING HEAT PUMP CONDENSER	27.3
COST OF TAP WATER HEAT PUMP CONDENSER	0.0
COST OF HOUSE HEATING HEAT PUMP EVAPORATOR	27.3
COST OF TAP WATER HEAT PUMP EVAPORATOR	0.0
COST OF HOUSE HEATING HEAT PUMP MOTOR	250.2
COST OF TAP WATER HEAT PUMP MOTOR	0.0
COST OF GROUND FOR STORE	0.0
INSTALLED COST FOR AUXILIARY HEATER (HOUSE)	320.6
INSTALLED COST OF AUXILIARY HEATER (TAP WATER)	0.0
COST OF COLLECTOR ARRAY PIPEWORK (CENTRAL)	474.0
COST OF COLLECTOR ARRAY PIPEWORK (HOUSE MOUNTED)	0.0
COST OF HOUSE HEATING DISTRIBUTION NETWORK	2250.0
COST OF TAP WATER DISTRIBUTION NETWORK	0.0

HEAT FLOW SUMMARY

COLLECTOR SUB-SYSTEM

COLLECTOR OUTPUT	10715.71 MWH	
CENTRAL COLLECTORS		
PIPE LOSS FORWARD	-2.16 MWH	
PIPE LOSS RETURN	5.41 MWH	
COLLECTOR SUPPLY		10712.46 MWH

STORAGE SUB-SYSTEM

STORAGE LOSSES	1811.14 MWH	
COLLECTOR SUPPLY MINUS STORAGE LOSSES		8901.32 MWH
STORED HEAT YEAR END		
MINUS YEAR BEGINNING	0.00 MWH	
COLLECTOR AND STORAGE SUPPLY		8901.32 MWH

AUXILIARY

HEAT PUMP ELECTRIC ENERGY		
HOUSE HEAT	3341.91 MWH	
TAP WATER	590.61 MWH	
AUXILIARY HEATER		
HOUSE HEAT	284.13 MWH	
TAP WATER	405.85 MWH	
TOTAL SUPPLY		13523.82 MWH

LOAD

DISTRIBUTION LOSS FORWARD		
HOUSE HEAT	388.03 MWH	
TAP WATER	0.00 MWH	
DISTRIBUTION LOSS RETURN		
HOUSE HEAT	174.26 MWH	
TAP WATER	0.00 MWH	
HOUSE LOAD	12961.52 MWH	
TOTAL LOAD		13523.82 MWH

ABOVE AUXILIARY FIGURES INCLUDE THE FOLLOWING AMOUNTS TO RAISE STORAGE WATER TO DUMPED TEMP.

HOUSE HEAT	0.00 MWH
TAPWATER	0.00 MWH

RATIOS

COLLECTOR SUPPLY/TOTAL LOAD	79.21 PERCENT
COLLECTOR SUPPLY MINUS STORAGE LOSSES/TOTAL LOAD	65.82 PERCENT
COLLECTOR AND STORAGE SUPPLY/TOTAL LOAD	65.82 PERCENT

TEMPERATURES OF STORAGE

START	8.0	8.0
END	10.6	8.0

CHANGE OF AVERAGE TEMPERATURE 1.300 C
MIN. TEMPERATURE 8.0 C MAX.TEMPERATURE 14.9 C
MIN CHANGE OF STORAGE 0.00 MWH MAX 0.00 MWH
DIAMETER OF CENTRAL COLLECTOR ARRAY PIPES 0.400 M
INSULATION THICKNESS ROUND PIPES 0.060 M

HEAT PUMP PERFORMANCE

	EL-MOTOR	COND POWER	C.O.P.
TAP WATER	590.61	2231.97	3.78
HOUSE HEAT	3341.91	10621.19	3.18

SPECIFIC COSTS

	INVESTMENT (CAN$/MWH/Y)	CAPITAL (CAN$/MWH)	OPERATION (CAN$/MWH)	TOTAL (CAN$/MWH)
SOLAR COLLECTORS	350.64	26.80	0.00	26.80
COLL. PIPEWORK	36.93	2.82	0.00	2.82
STORAGE	19.48	1.49	0.00	1.49
HEAT PUMP	23.76	1.82	6.85	8.67
TOTAL SOLAR SYSTEM	430.80	32.92	6.85	39.77
AUXILIARY	464.67	35.51	18.71	54.22
TOTAL SYSTEM	432.53	33.05	7.46	40.51

TOTAL SOLAR COST (/MWH DELIVERED FROM SOLAR SYSTEM) 47.47

AQUIFER PERFORMANCE

MAXIMUM RADIUS OF STORAGE (M)	129.72
MAXIMUM VOLUME OF STORAGE (000 M**3)	1057.24
FINAL RADIUS OF STORAGE (M)	10.25
NET VOLUME OF WATER INJECTED INTO STORAGE (000 M**3)	6.60
AVERAGE TEMPERATURE OF INJECTED WATER (C)	15.00
TOTAL INJECTED VOLUME (000 M**3)	1326.01
AVERAGE EVAPORATOR FEED TEMPERATURE - HOUSE (C)	13.42
AVERAGE EVAPORATOR DUMP TEMPERATURE - HOUSE (C)	7.90
AVERAGE TEMPERATURE DROP ACROSS EVAPORATOR (C)	5.51
VOLUME DUMPED FROM EVAPORATOR (000 M**3)	1136.83
AVERAGE DISTRIBUTION FEED TEMPERATURE - HOUSE (C)	0.00
AVERAGE DISTRIBUTION DUMP TEMPERATURE - HOUSE (C)	0.00
AVERAGE TEMP DROP ACROSS DISTRIBUTION SYSTEM (C)	0.00
VOLUME DUMPED FROM DISTRIBUTION SYSTEM (000 M**3)	0.00
AVERAGE EVAPORATOR FEED TEMPERATURE - TAPWATER (C)	14.47
AVERAGE EVAPORATOR DUMP TEMPERATURE - TAPWATER (C)	7.12
AVERAGE TEMPERATURE DROP ACROSS EVAPORATOR (C)	7.35
VOLUME DUMPED FROM EVAPORATOR (000 M**3)	192.22
AVERAGE DISTN FEED TEMPERATURE - TAPWATER (C)	0.00
AVERAGE DISTN DUMP TEMPERATURE - TAPWATER (C)	0.00
AVERAGE TEMP DROP ACROSS DISTRIBUTION SYSTEM (C)	0.00
VOLUME DUMPED FROM DISTRIBUTION SYSTEM (000 M**3)	0.00